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**PREDICTION OF SOUND RADIATION FROM
DIFFERENT PRACTICAL JET ENGINE INLETS**

By

Ben T. Zinn

William L. Meyer



GEORGIA INSTITUTE OF TECHNOLOGY

A UNIT OF THE UNIVERSITY SYSTEM OF GEORGIA

SCHOOL OF AEROSPACE ENGINEERING

ATLANTA, GEORGIA 30332

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Ben T. Zinn

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William L. Meyer

SCHOOL OF AEROSPACE ENGINEERING
GEORGIA INSTITUTE OF TECHNOLOGY
ATLANTA, GA. 30332

ABSTRACT

This report summarizes the work performed during the second six month period of the NASA Lewis sponsored research program (Contract Number NAG 3-67) entitled "Prediction of Sound Radiation from Different Practical Jet Engine Inlets". During the initial six month period of the contract the computer codes necessary for this study were developed and checked against exact solutions using the NASA Lewis QCSEE inlet geometry. This research is summarized in the Semi-Annual Status Report (6/2/80 - 11/30/80).

During the past six months the developed computer codes were used to predict the acoustic characteristics of the following five inlet configurations: the NASA Langley Bellmouth, the NASA Lewis JT15D-1 Ground Test Nacelle and three hyperbolic inlets of 50, 70 and 90 degrees. Various calculations have been done on each so that comparisons with the results of other experimental and theoretical studies could be made. In this report both reflection coefficients and radiation patterns calculated by the integral solution procedure developed here at Georgia Tech are compared with the results of other experimental and theoretical studies.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
THE LANGLEY BELLMOUTH	3
THE LEWIS JT15D-1 GROUND TEST NACELLE	10
THE 50 DEGREE HYPERBOLODIAL INLET	12
THE 70 DEGREE HYPERBOLODIAL INLET	14
THE PLANE BAFFLE	16
CONCLUSIONS	19
REFERENCES	21
TABLES	23
FIGURES	28

INTRODUCTION

This research program consists of two major tasks. The first task was the upgrading, development and testing of computer codes for the calculations of the radiation patterns associated with various axisymmetric inlet configurations. The idea was to develop computer codes capable of producing accurate results for non-dimensional wave numbers (based on duct radius) of up to 20. The initial computer development work was done on the NASA Lewis QCSEE inlet of Ref. 1. The results of this work are presented in the NASA Lewis Semi-Annual Status Report (6/2/80 - 11/30/80) for Grant Number NAG 3-67.

The second task was to use the computer codes developed during the first six months of the contract to generate results for various other inlet configurations. These results were to be compared with those of theoretical and experimental studies performed elsewhere for the same inlet configurations. The inlet configurations used in the second part of this study were: the NASA Langley Bellmouth^{2,3}; the NASA Lewis JT15D-1^{4,5} and three of the hyperbolic inlets of the Y.C. Cho^{6,7} study of 50, 70 and 90 degrees. Although the main objective of this study was to compare the radiation patterns generated by the integral technique⁸⁻¹⁰ with those calculated and measured in other experimental and theoretical studies the reflection coefficients were also calculated and compared for certain specific inlet configurations where other results were available. These comparisons were not expected to yield particularly good agreement as it has been shown by the authors that reflection coefficients (or admittances)

calculated by different methods do not necessarily yield the same values¹¹ even for the same geometries.

In addition to the above work, the authors have also published a paper¹² during the reporting period. This paper provides comparisons between experimentally measured and theoretically calculated results for the NASA Lewis QCSEE inlet (employed during the first six month reporting period for this contract). The paper shows that very good agreement was obtained between measured and calculated acoustic radiation patterns. This particular study was conducted under AFOSR support and additional results are presented in the final technical report for that agency¹³.

THE LANGLEY BELLMOUTH

The geometry for the Langley Bellmouth was obtained directly from R. J. Silcox as the cone angle of 57 degrees given in Ref. 2 is incorrect. The actual cone angle is closer to 56 degrees. Computer runs done for this inlet configuration utilized 102 points on the surface of the body where the acoustic quantities of interest, the acoustic potential and normal acoustic velocity, were calculated. The geometrical input data for this inlet is plotted in Fig.1 where the arrows represent the normals to the body at the various points on the body. The open circles are the points where the acoustic quantities are calculated and the locations denoted by small crosses are those used in the integration procedure. Since the theory requires a closed body, the outer wall of the inlet was approximated by part of a smaller ellipse centered at the same point as the larger inner lip ellipse. Also, the body was terminated by an ellipse.

The choice of these curves is relatively arbitrary as it has been shown by the authors in previous studies that the specific termination given to a body to "close it off" does not significantly affect the acoustic radiation in the forward half plane.

Next, the boundary conditions utilized in this study need to be considered. In all of the investigated cases, the acoustic potential was specified along the driver surface and a zero normal acoustic velocity was specified (i.e., the body is assumed to have acoustically hard walls) along the remaining surfaces. Also, when the acoustic reflection coefficient is calculated it is done at the driver surface (e.g. on the body). The complex

reflection coefficient used in this study is defined as

$$R = \frac{ik\varphi - \frac{\partial\varphi}{\partial n}}{ik\varphi + \frac{\partial\varphi}{\partial n}} \quad (1)$$

where k is the wave number, φ is the acoustic potential and $\frac{\partial\varphi}{\partial n}$ is the outward normal acoustic velocity.

A list of the computer runs done for this geometry is included in Table I. The right hand column refers to the number of points used in the Gauss-Legendre integration in the tangential direction. A two point integration is always used along the body. For each case run, a standard plot is produced by the computer program of the Sound Pressure Level in decibels (i.e., SPL in dB) at a distance of $20.36a$ from the exit plane of the inlet where a is the radius at the driver plane. This distance was chosen so that direct comparisons could be made with the results presented in Ref. 3. These plots, for the Langley Bellmouth, are presented in Figs. 2-14. The SPL was calculated at 2 degree intervals from 0 degrees (i.e., the centerline of the inlet) to 90 degrees. In the small table in each figure any dB level that was calculated to be less than -99 dB is printed as a zero.

For the Langley Bellmouth there are 25 points on the driver plane. Since there is no straight duct section connected to the inlet in the theoretical model (See Fig. 1.) the driver plane is where the reflection coefficient is calculated. The boundary condition on the driver plane is specified as the acoustic potential for the transverse mode of interest, and the normal acoustic velocity at this plane is determined by the solution. The reflection coefficient is then calculated using Eqn. 1.

Direct comparisons with the data presented in Ref. 3 for the reflection coefficient is difficult as one value of the reflection coefficient is presented for each tangential mode at each non-dimensional wave number, ka , whereas the integral solution procedure yields a value at each point across the duct. In Figs. 15 and 16 the non-dimensional wave number is held constant and the tangential mode number is varied. When compared to the results presented in Ref. 3 (Fig. 16.) it is noted that the reflection coefficients calculated in the present study have moduli that are uniformly high. This is consistently found to be the case for this inlet. The Cho theory (See Ref. 7.) also predicts the reflection coefficients moduli to be consistently higher than the measured data with the present results being even higher. It should be noted, however, that the present results do predict the correct trend in that as the tangential mode number is increased the modulus of the reflection coefficient increases and the phase angle of the reflection coefficient decreases. It also needs to be pointed out that values close to the centerline of the duct are probably in error for tangential modes greater than zero due to the relatively small values of the acoustic potential there, and values close to the wall probably contain errors due to the proximity of the sharp corners (a common fault with most potential type solution procedures -- leakage at sharp corners).

In Figs. 17 and 18 results are presented for the modulus and phase respectively for a tangential mode number of 4 and a non-dimensional wave number of 5.81. Similarly, in Figs. 19 and 20 results are presented for $M = (6,0)$ and $ka = 11.14$. Again, the calculated values are higher than either the Cho or experimentally derived values.

In Figs. 21 and 22 the modulus and phase of the reflection coefficient are plotted holding the tangential mode number constant, $M = (1,0)$, and varying the non-dimensional wave number. Although the results of this analysis are high, the values show the correct trends as for increasing non-dimensional wave number the modulus of the reflection coefficient decreases while the phase increases. Similarly, in Figs. 23 and 24, where the tangential mode is $M = (2,0)$, the same trends are observed.

One of the characteristics of the integral solution procedure is that results obtained in the field surrounding a given body are generally better than those obtained on the body itself. This is thought to be due to the fact that an acoustic quantity calculated at a point on the body is actually an average value of the quantity over the integration area associated with that point. Therefore, direct point comparisons, especially where the acoustic quantity of interest varies significantly over the integration area (e.g., near the centerline of the duct for tangential mode numbers greater than zero), usually do not yield extremely good agreement. However, when calculating acoustic quantities in the field surrounding the body at a specific point a simple summation or integral of the acoustic quantities on the surface of the body is performed. In this case better point results are obtained in the field if average, not point, values are known on the body which turns out to be the case. Thus, it is expected that better agreement will be found with the experimental results presented in Ref. 3 for the quantities measured in the field surrounding the body. Also, good agreement between experiment and theory has already been shown in the study of the NASA Lewis QCSEE inlet performed for AFOSR and presented in Ref. 12.

In Fig. 25 the relative SPL in the field on a circle centered at the exit plane of the Langley Bellmouth at a radius of $20.36a$ is presented for $M = (0,0)$ and $ka = 1.39$. The points calculated were at 2 degree increments from the centerline to 90° . This plot should be compared with Fig. 17 of Ref. 3. Due to the waviness of this experimentally derived data it is subject to some interpretation and therefore a range of values shall be presented here when discussing it. If the data is arbitrarily smoothed in Fig. 17 of Ref. 3 it is found that there is approximately a 10-15 dB drop between 0 and 90° whereas the present analysis (See Fig. 25.) yields a 12 dB drop. Figures 26-28 should also be compared with Fig. 17 of Ref. 3. For $M = (0,0)$ and $ka = 3.76$ it is estimated from the experimental data that there is a 25-30 dB drop from 0 to 90° and it is found that the present analysis yields a 27 dB drop. (It will be noted again here that Figs. 2-14 have small SPL (dB) tables associated with them so that these relative SPL (dB) values may be easily calculated.) Also, the curve flattens towards the horizontal at 90° in Fig. 26 as it does in Fig. 17 of Ref. 3. In Fig. 27 the mode number is $M = (1,0)$ and the non-dimensional wave number is $ka = 2.66$. It is found that the maximum SPL (dB) for this case occurs at 32° from the centerline and that there is a 12 dB drop from this peak to 90° . From the experimental data it is estimated that the peak lies between 25 and 35° and that there is a 10-15 dB drop from there to 90° . Finally from Fig. 17 of Ref. 3 for $M = (1,0)$ and $ka = 5.29$ it is estimated that the radiation peak is between 15 and 25° and that there is a 20-25 dB drop from the peak to 90° . In Fig. 28 for the same case it is found that the peak is at 22° and that there is a 22 dB drop from there to 90° .

As can be seen the experimental data of Ref. 3 and the theoretically calculated data of this study compare very well in the field surrounding the body even though there was rather poor comparison between the reflection coefficients. Since the integral technique does not require the calculation of reflection coefficients to generate results in the field this is not considered a significant short-coming of the method.

Figures 29 and 30 are presented for comparison with Fig. 24 of Ref. 3. Experimentally the first peak for the case where $M = (2,0)$ and $ka = 3.37$ lies very close to 40° and the dB drop for the case is found to be about 10 dB. Theoretically the peak is found to be at 42° and the dB drop from there to 90° is found to be 9 dB. Similarly, the experimental radiation peak for $M = (2,0)$ and $ka = 4.40$ is found to be between 30 and 40° from the centerline of the duct and from there to 90° the dB drop is measured to be between 10 and 15 dB. In the present study these are found to be 36° and 13 dB respectively; again showing excellent correlation with the experimental results of Ref. 3.

For the higher mode number of $M = (4,0)$ only one plot of the radiation pattern in the field surrounding the Langley Bellmouth is given. This is found in Fig. 24 of Ref. 3 for $ka = 5.81$. From this experimental data plot it is estimated that the first radiation peak occurs between 40 and 50° from the centerline of the duct and that there is a 10-15 dB drop from this point to 90° . Theoretically, (See Fig. 31.) these are calculated to be 46° and 11 dB respectively.

Figures 32 and 33 are presented for comparison with Fig. 20 of Ref. 3. A summary of the radiation results presented thus far are presented in

Table II. Also, for comparison with the "concept of angular location of predominant acoustic radiation" set forth in Ref. 3 the angular location of the 6 dB down points are tabulated for all the cases run in Table III. This table should be compared with Fig. 19 of Ref. 3.

The relative phase of the radiation in the field is plotted for three cases in Figs. 34-36. The term relative phase is used here as the phase was referred to the phase at the maximum SPL (dB) point for the amplitude in the field. This occurred at zero degrees in the first plot (See Fig. 34.) as it is for the plane wave, $M = (0,0)$ mode. This figure may be compared with Fig. 21 of Ref. 3. Doing this it is found that the phase variation between the centerline of the duct and 90° is about 90° for the experimental results of Ref. 3 whereas the calculated phase variation is much less. In Fig. 35 the phase is referred to that at 38° degrees from the centerline. If this plot is compared to the experimental data presented in Fig. 25 of Ref. 3 it is again found that the theory predicts much less variation in the phase. Similarly, if Fig. 36 is compared to Fig. 21 of Ref. 3 the theory again predicts less variation than is found experimentally. The phase in Fig. 36 is referenced to that at 32° .

THE LEWIS JT15D-1 GROUND TEST NACELLE

The geometry for the Lewis JT15D-1 was obtained directly from the blue-prints used in its manufacture. The driver plane for the theoretical studies was placed at the junction of the curved inlet section and the straight duct as was done with the Langley Bellmouth. For the computer runs 175 points were used on the body and for the tangential integration a 96 point Gauss-Legendre integration scheme was used in all cases due to the relatively high tangential mode number $M = (13,0)$ that was investigated. The geometrical input data for the computer runs is presented in Fig. 37. The inlet lip geometry consists of 3 circular arcs and is terminated smoothly with an ellipse as with the Langley Bellmouth.

The two non-dimensional wave numbers of interest are $ka = 15.51$ and $ka = 19.42$ and results for the SPL in dB radiated into the field are presented in Figs. 38 and 39, respectively. As with the Langley Bellmouth these results are calculated on a circular arc at 2° increments from the centerline to 90° which has a radius of $20.36a$ and is centered at the inlet lip exit plane. Again, any SPL dB level less than -99 is represented in the small tables in Figs. 38 and 39 as zero. Also, the values are truncated, not rounded, in the tables (e.g., In Fig. 38 at 14° from the centerline the value is 20.9 and thus the visible offset in the plot.).

In Figs. 40-43 the modulus and phase of the reflection coefficient at the driver plane of the duct is presented for both cases run. As can be seen from the input geometry in Fig. 37, there are 50 points on the driver plane where these are calculated. As before, the first few points near the

centerline of the duct must be neglected due to the extremely low dB levels there and very close to the wall (i.e., the sharp corner) they must be neglected also.

In Figs. 44-47 the relative SPL in dB in the field and the relative phase (referred to the maximum SPL point) are presented for the two cases of interest. The SPL peaks show the proper trend as the higher wave number case yields the peak radiation closer to the centerline (See Fig. 19 of Ref. 5.).

THE 50 DEGREE HYPERBOLOIDAL INLET

The geometry used for the following computations is presented in Fig. 48. Since the integral equation technique used in the present study requires a closed, finite body the hyperbolic inner lip of the body had to be terminated at some finite distance. Since the results of the computations will be compared with those of the Y. C. Cho theory⁷ this is a very important approximation as the Cho theory considers an infinite hyperbolic horn. The hyperbolic inner lip was terminated with a semi-circle; the outer lip is the same hyperbola as that of the inner lip except that it is shifted, and, the body is again terminated with an ellipse.

A summary of the computer runs done for this geometry is presented in Table IV. Since all the runs for this geometry are for $M = (0,0)$ and all of the non-dimensional wave numbers are relatively small (i.e., less than 5) 32 points were used for the tangential integration in all cases.

For all of the cases run for this geometry the SPL in dB radiation patterns are presented in Figs. 49-54. For these calculations the circle on which the patterns are calculated in the field is centered at the driver plane of the inlet and not at the exit plane as previously done. Also, the radius of the circle is $20a$ (where a is the radius of the duct at the driver plane) and as before the field quantities are calculated every 2 degrees.

In Fig. 55 the modulus of the reflection coefficient is plotted for all of the cases run for this geometry. Note that a single value of the reflection coefficient is not obtained but rather a series of values across the duct exit plane (i.e., the driver plane for the present study). Since the non-dimensional wave numbers are so low, essentially constant distributions are obtained.

Furthermore, when Fig. 55 is compared with Fig. 4 of Ref. 7 very good agreement is found.

In Fig. 56 the phase of the reflection coefficient is presented for all of the investigated cases. As can be seen, the distributions of the phase of the reflection coefficient do not lend themselves to average values as readily as the modulus did, except for very low values of the non-dimensional wave number (e.g. $ka < 1.0$). For these values good agreement is found between the Cho theory of Ref. 7 (See Fig. 4.) and the present study. For the higher wave number cases no reasonable comparison is possible.

In Fig. 57 the relative SPL in dB in the field, at $20a$ from the driver plane (exit plane) of the duct is presented. Although direct comparisons cannot, by virtue of its formulation, yield values outside 50° from the duct axis. In Fig. 58 the relative phase of the radiated field is presented for completeness.

THE 70 DEGREE HYPERBOLOIDAL INLET

The geometry used for calculations in this study for the 70° hyperboloidal inlet is presented in Fig. 59. Its makeup is similar to that of the 50° hyperboloidal inlet of the previous section (See Fig. 48.). This inlet is also an approximation of one of the inlets that Y. C. Cho presented in Ref. 7. Three specific cases were run for this configuration; specifically, $M = (8,0)$ and $ka = 9.7, 12.0$ and 16.0 . For all three of these cases a 64 point Gauss-Legendre integration formula was employed for the integration in the tangential direction. The standard computer plots of the SPL in dB in the field on a quarter circle centered at the driver (exit) plane of the duct at a radius of $20a$ are presented in Figs. 60-62. As before, the quantities of interest in the field were calculated at 2 degree increments from the centerline to 90° .

In Figs. 63 and 64 the modulus and phase of the reflection coefficient at the driver (exit) plane of the 70° hyperboloidal inlet are presented. These figures should be compared with Fig. 5 of Ref. 7 for $ka = 9.7$ and $ka = 12.0$. In both cases the modulus of the reflection coefficient as calculated in this study seems to be high when compared to the Cho theory. Similarly, the phase is also high.

In Figs. 65 and 66 the relative SPL and phase in the field are presented. The SPL plot should be compared with Fig. 10 of Ref. 7. In the present study the radiation peaks occur earlier than in the Cho theory for $ka = 9.7$ and 12.0 ; however, the peak for $ka = 16.0$ is very close. The plot of relative phase (See Fig. 66.) is presented for completeness. When analyzing

these phase data, one should bear in mind that the sharp peaks are not actually there as the curves should continue smoothly from -180° to $+180^{\circ}$ and vice versa near 90° from the centerline of the duct.

THE PLANE BAFFLE

The approximation to the geometry of the plane baffle employed in the present study is presented in Fig. 67. In this figure the non-dimensional length a (the radius of the driver) is shown explicitly. The top edge of the plane baffle is a quarter circle and the body is terminated by an ellipse.

There were 14 separate cases run for this geometry and they are presented in Table V. The standard computer plots for the SPL in dB generated in the field for the first set of cases (i.e., those for which $M = (0,0)$) are given in Figs. 68-71.

In Figs. 72 and 73 the modulus and phase of the reflection coefficient for the plane baffle for all of the cases run where $M = (0,0)$ are given. This should be compared with Fig. 4 of Ref. 7. The modulus plots compare very well with each other even though in the present study the reflection coefficient is strictly a function of position as the curves generated are almost constant across a large portion of the exit (driver) plane. The phase plots cannot be compared as easily, as in the present study it is found that the phase of the reflection coefficient changes drastically over the exit plane.

For the sake of completeness the relative SPL in dB and phase in degrees of the radiated field are presented for the cases where $M = (0,0)$ in Figs. 74 and 75.

The standard computer plot for SPL in the field is presented in Fig. 76 for the case where $M = (0,1)$ and $ka = 3.0$. If this is compared with Fig. 12 of Ref. 7 it is found that the present study does not predict the side lobe at 90° to be greater than the principle lobe at 0° (i.e., on the centerline of the

duct). It is felt that this is due in part to the fact that in the present study there is radiation in the backward half plane (i.e., from 90° to 180°) because the body is a finite plane baffle and not an infinite one as in the Cho study.

The modulus and phase of the reflection coefficient is given for this case in Figs. 77 and 78. Also, the modulus and phase of the radiated field at $20.0a$ from the center of the driver plane is given in Figs. 79 and 80 for this case.

In Figs. 81-85 the standard computer plots for the SPL in the field is presented for the cases where $M = (8,0)$ for the plane baffle.

In Figs. 86 and 87 the modulus and phase of the reflection coefficient for the plane baffle for the cases where the $M = (8,0)$ mode is input at the driver plane are presented. These plots should be compared with Fig. 5 of Ref. 7. Doing this it is found that although the results of the present study do not yield average values directly (i.e., the curves vary significantly across the exit plane) both the modulus and phase of the reflection coefficient do show the same trends.

The relative SPL in the field is presented in Fig. 88 for these cases. If these results are compared with Fig. 14 of Ref. 7 it can be seen that the radiation peaks occur very close to the same angular locations in the field. The relative phase in the field is presented in Fig. 89 for completeness. In viewing this plot, one should recall that the widely varying top to bottom curves actually represent rather smooth curves as they pass from -180° to $+180^\circ$ and vice versa.

The standard computer plots of SPL in the field surrounding the plane baffle for all of the cases run for $M = (8,1)$ are presented in Figs. 90-93. These plots, along with Figs. 82-85 should be compared with Fig. 15 of Ref. 7. Doing this, it is found that the present study again does not predict the large side lobes that the Cho study does; however, as before, this is thought to be due to the differences in the geometries used for the calculations.

The modulus and phase of the reflection coefficient for the cases where $M = (8,1)$ are presented in Figs. 94 and 95 respectively. Also, the relative SPL and phase in the field are presented for these cases in Figs. 96 and 97. These four plots are merely included for completeness.

CONCLUSIONS

Results of theoretical predictions, based upon the utilization of integral solution techniques, of the radiated sound patterns associated with different engine inlets are presented in this report. The predictions of the present study compare very well with experimental data describing the radiated sound field around the Langley Bellmouth. This observation is consistent with earlier comparisons performed by the authors of the present study for experimental and theoretical results obtained for the QCSEE inlet^{12,13}. In contrast, the predicted admittance values (i.e., reflection coefficients) at the duct exit plane for this same inlet did not compare very well with corresponding experimental results. In this case, both sets of data showed the same trends but quantitative agreement was lacking. Such lack of agreement between theoretical admittance data calculated by different methods was also observed by the authors in an earlier study of admittances at a duct termination¹¹.

The results generated in the present study for comparison with the Cho⁶⁻⁷ theory only showed a qualitative agreement in most cases. The authors feel that this is probably due to the different geometries used in the two studies more than any inherent errors in either of the solution approaches. In the Cho theory an infinite body is used while in the present study the acoustic characteristics of a finite, closed body is investigated. This is significant as the authors have also shown that seemingly small changes in the geometry of an acoustic radiator can result in large changes in its radiated sound field.¹⁴

The predictions of the method used in the present study have been shown to compare very favorably with exact solutions generated by the "point source method" for complicated geometries and have also been shown to compare very well with experimental data. The present approach also has the capability of predicting the acoustic properties of geometries which have acoustically soft or lined walls where these can be represented by an acoustic admittance on the body. Thus, the method used in the present study has been shown to be a powerful tool which can be used to predict the effect of changes in either the geometry or acoustic properties of the body on the radiated sound field without having to use the artifice of reflection coefficients at a duct exit plane which may or may not be of value depending upon how they are calculated.

REFERENCES

- 1) "Effect of Entry-Lip Design on Aerodynamics and Acoustics of High-Throat-Mach-Number Inlets for the Quiet, Clean, Short-Haul Experimental Engine," B. A. Miller, B. J. Dastoli and H. L. Wesoky, NASA TM X-3222, May 1975.
- 2) "Inlet Contour and Flow Effects on Radiation," J. M. Ville and R. J. Silcox, AIAA Paper Number 80-0966, June 1980.
- 3) "Experimental Investigation of the Radiation of Sound from an Unflanged Duct and a Bellmouth Including the Flow Effect," J. M. Ville and R. J. Silcox, NASA Technical Paper 1697, August 1980.
- 4) "Analysis of Radiation Patterns of Interaction Tones Generated by Inlet Rods in the JT15D Engine," M. F. Heidmann, A. V. Saule and J. G. McArdle, AIAA Paper Number 79-0581, March 1979.
- 5) "Analysis of Radiation Patterns of Interaction Tones Generated by Inlet Rods in the JT15D Engine," M. F. Heidmann, A. V. Saule and J. G. McArdle, NASA TM-79074, March 1979.
- 6) "Sound Radiation from Hyperboloidal Inlet Ducts," Y. C. Cho, AIAA Paper Number 79-0677, March 1979.
- 7) "Rigorous Solutions for Sound Radiation from Circular Ducts with Hyperbolic Horns or Infinite Plane Baffle," Y.C. Cho, Journal of Sound and Vibration, Vol 69, No. 3, pp. 405-425, 1980.

- 8) "Predicting the Acoustics of Arbitrarily Shaped Bodies Using an Integral Approach," W. A. Bell, W. L. Meyer and B. T. Zinn, AIAA Journal, Vol. 15, No. 6, pp. 813-820, June 1977.
- 9) "Boundary Integral Solutions of Three Dimensional Acoustic Radiation Problems," W. L. Meyer, W. A. Bell, M. P. Stallybrass and B. T. Zinn, Journal of Sound and Vibration, Vol. 59, No. 2, pp. 245-262, July 1978.
- 10) "Prediction of the Sound Field Radiated from Axisymmetric Surfaces," W. L. Meyer, W. A. Bell, M. P. Stallybrass and B. T. Zinn, Journal of the Acoustical Society of America, Vol. 63, No. 2, pp. 631-638, March 1979.
- 11) "Sound Radiation from Ducts: A Comparison of Admittance Values," W. L. Meyer, W. A. Bell and B. T. Zinn, TECHNICAL NOTE, AIAA Journal, Vol. 18, No. 12, pp. 1538-1540, December 1980.
- 12) "Acoustic Radiation from Axisymmetric Ducts: A Comparison of Theory and Experiment," W. L. Meyer, B. R. Daniel and B. T. Zinn, AIAA Journal, Vol. 18, No.3, pp. 317-323, March 1981.
- 13) "Noise Suppression in Jet Inlets," B. T. Zinn, W. L. Meyer and B. R. Daniel, AFOSR Final Technical Report, AFOSR-TR-80-0452, February 1980.
- 14) "Sound Radiation from Finite Length Axisymmetric Ducts and Engine Inlets," W. L. Meyer, W. A. Bell and B. T. Zinn, AIAA Paper Number 79-0675, presented at the AIAA 5th Aeroacoustics Conference, Seattle, Washington, March 12-14, 1979.

TABLE I

COMPUTER RUNS DONE FOR LANGLEY BELLMOUTH

MODE (TANGENTIAL, RADIAL)	NON-DIMENSIONAL WAVE NUMBER ka	NUMBER OF POINTS IN TANGENTIAL INTEGRATION
(0,0)	1.39	32
(0,0)	3.76	32
(1,0)	1.91	64
(1,0)	2.03	64
(1,0)	2.66	64
(1,0)	3.76	64
(1,0)	5.29	64
(2,0)	3.37	64
(2,0)	3.76	64
(2,0)	4.40	64
(2,0)	5.29	64
(4,0)	5.81	64
(6,0)	11.14	96

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TABLE II

RADIATION RESULTS FOR THE LANGLEY BELLMOUTH

MODE NUMBER	WAVE NUMBER	POSITION OF PRINCIPLE RADIATION LOBE (Deg.)		dB DROP FROM PRINCIPLE LOBE TO 90 DEGREES	
		Ref. 3	Present Study	Ref. 3	Present Study
(0,0)	1.39	0	0	10-15	12
(0,0)	3.76	0	0	25-30	27
(1,0)	1.91	35-45	38	5-10	7
(1,0)	2.66	25-35	32	10-15	12
(1,0)	3.76	20-30	26	12-17	15
(1,0)	5.29	15-25	22	20-25	22
(2,0)	3.37	35-45	42	8-13	9
(2,0)	3.76	30-40	38	8-13	10
(2,0)	4.40	30-40	36	10-15	13
(2,0)	5.29	25-35	32	13-18	16
(4,0)	5.81	40-50	46	10-15	11

TABLE III

THE CONCEPT OF ANGULAR LOCATION OF PREDOMINANT ACOUSTIC RADIATION
FOR THE LANGLEY BELLMOUTH

MODE NUMBER M	WAVE NUMBER ka	f / f_{mn}	ψ_{MIN} (-6dB) (Degrees)	ψ_{MAX} (-6dB) (Degrees)
(0,0)	1.39	∞	---	55
(0,0)	3.76	∞	---	29
(1,0)	1.91	1.04	12	87
(1,0)	2.03	1.10	12	82
(1,0)	2.66	1.44	10	68
(1,0)	3.76	2.04	8	55
(1,0)	5.29	2.87	7	44
(2,0)	3.37	1.10	19	79
(2,0)	3.76	1.23	18	72
(2,0)	4.40	1.44	16	65
(2,0)	5.29	1.73	15	58
(4,0)	5.81	1.07	26	54
(6,0)	11.14	1.49	26	59

TABLE IV

COMPUTER RUNS DONE FOR THE 50 DEGREE HYPERBOLOIDAL INELT

MODE (TANGENTIAL, RADIAL)	NON-DIMENSIONAL WAVE NUMBER ka	NUMBER OF POINTS IN TANGENTIAL INTEGRATION
(0,0)	0.1	32
(0,0)	0.5	32
(0,0)	1.0	32
(0,0)	2.5	32
(0,0)	3.83	32
(0,0)	4.5	32

TABLE V

COMPUTER RUNS DONE FOR THE PLANE PAFFLE

MODE (TANGENTIAL, RADIAL)	NON-DIMENSIONAL WAVE NUMBER ka	NUMBER OF POINTS IN TANGENTIAL INTEGRATION
(0,0)	1.0	32
(0,0)	2.0	32
(0,0)	3.0	32
(0,0)	3.83	32
(0,1)	3.0	32
(8,0)	9.7	96
(8,0)	12.0	96
(8,0)	13.5	96
(8,0)	14.5	96
(8,0)	16.0	96
(8,1)	12.0	96
(8,1)	13.5	96
(8,1)	14.5	96
(8,1)	16.0	96

TABLE 9

COMPUTER RUNS DONE FOR THE PLANE TOWLE

MODE: (TANGENTIAL, RADIAL)	NON-DIMENSIONAL WAVE NUMBER Fo	NUMBER OF POINTS IN CONVECTION INTEGRATION
(0,0)	1.0	32
(0,0)	2.0	32
(0,0)	4.0	32
(0,0)	3.83	32
(0,1)	2.0	32
(8,0)	9.7	96
(8,0)	12.0	96
(8,0)	13.5	96
(8,0)	14.5	96
(8,0)	16.0	96
(8,1)	12.0	96
(8,1)	13.5	96
(8,1)	14.5	96
(8,1)	16.0	96

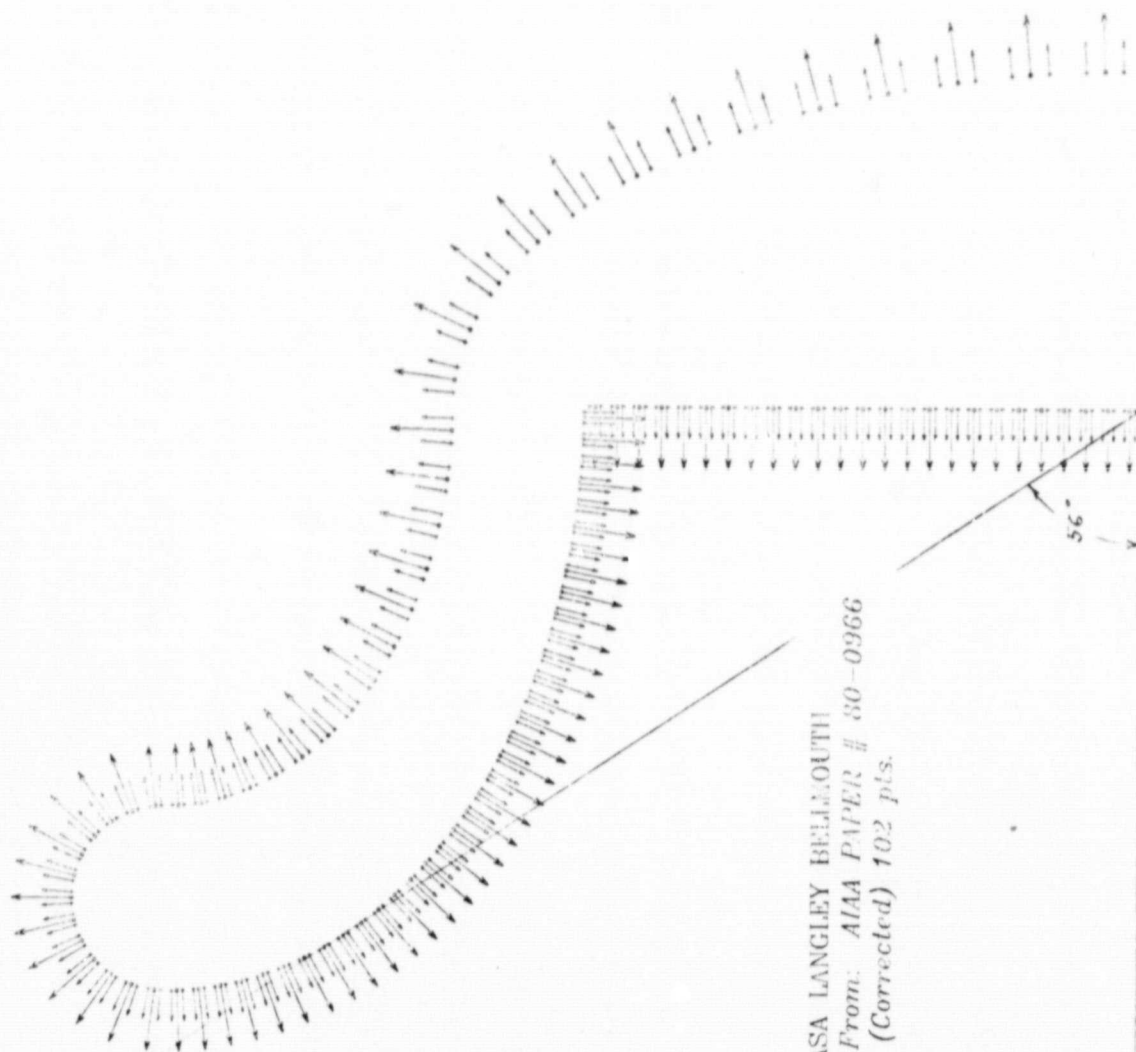
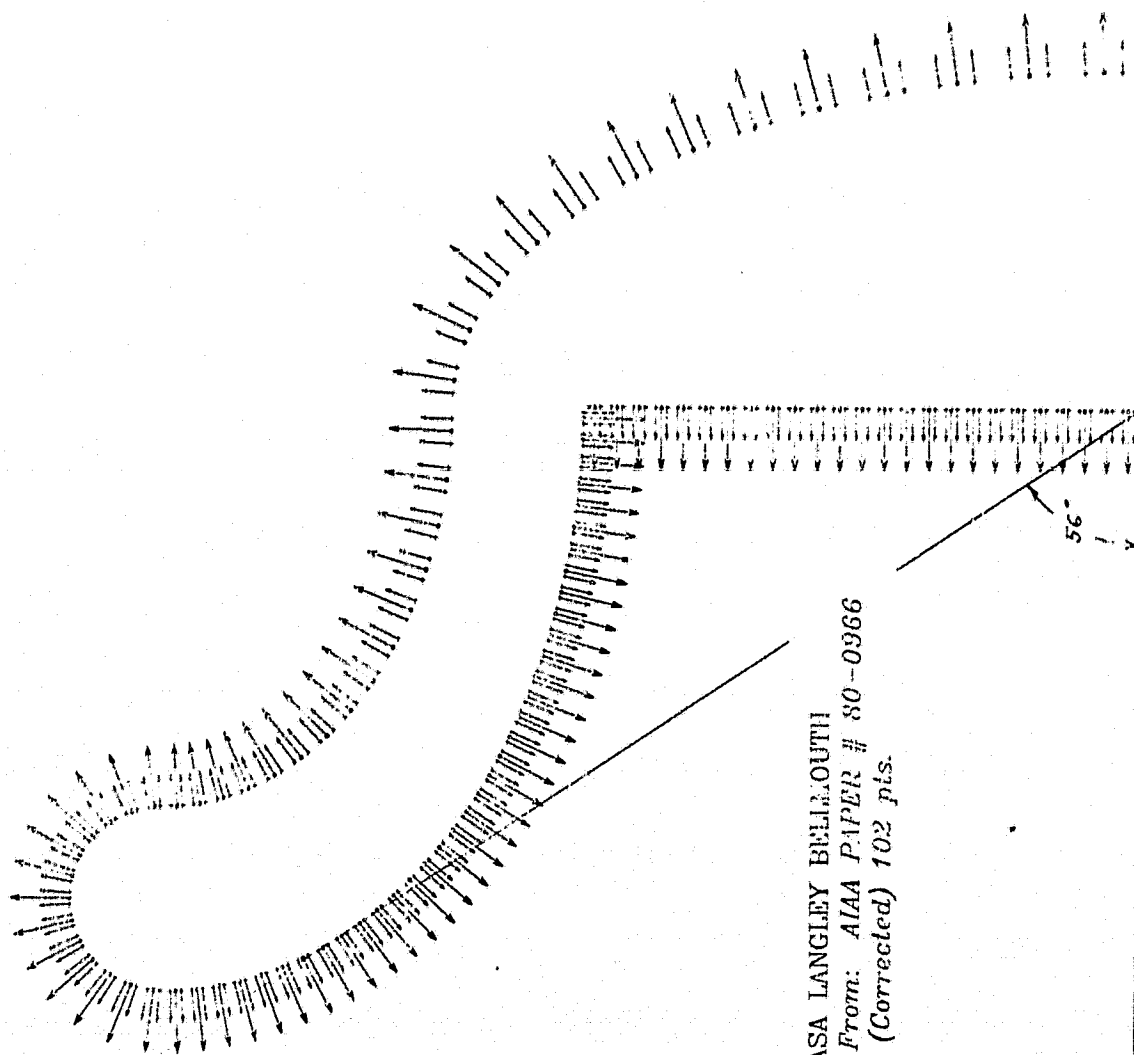


Fig. 1 Langley Bellmouth Geometry used for Computer Calculations.



NASA LANGLEY BELLMOUTH
Geometry From: AIAA PAPER # 80-0966
(Corrected) 102 pts.

Fig. 1 Langley Bellmouth Geometry used for Computer Calculations.

LANGLEY BFLM MOUTH

$ka = 1.39$
 $M = 0$
 $\bullet 20.36a$

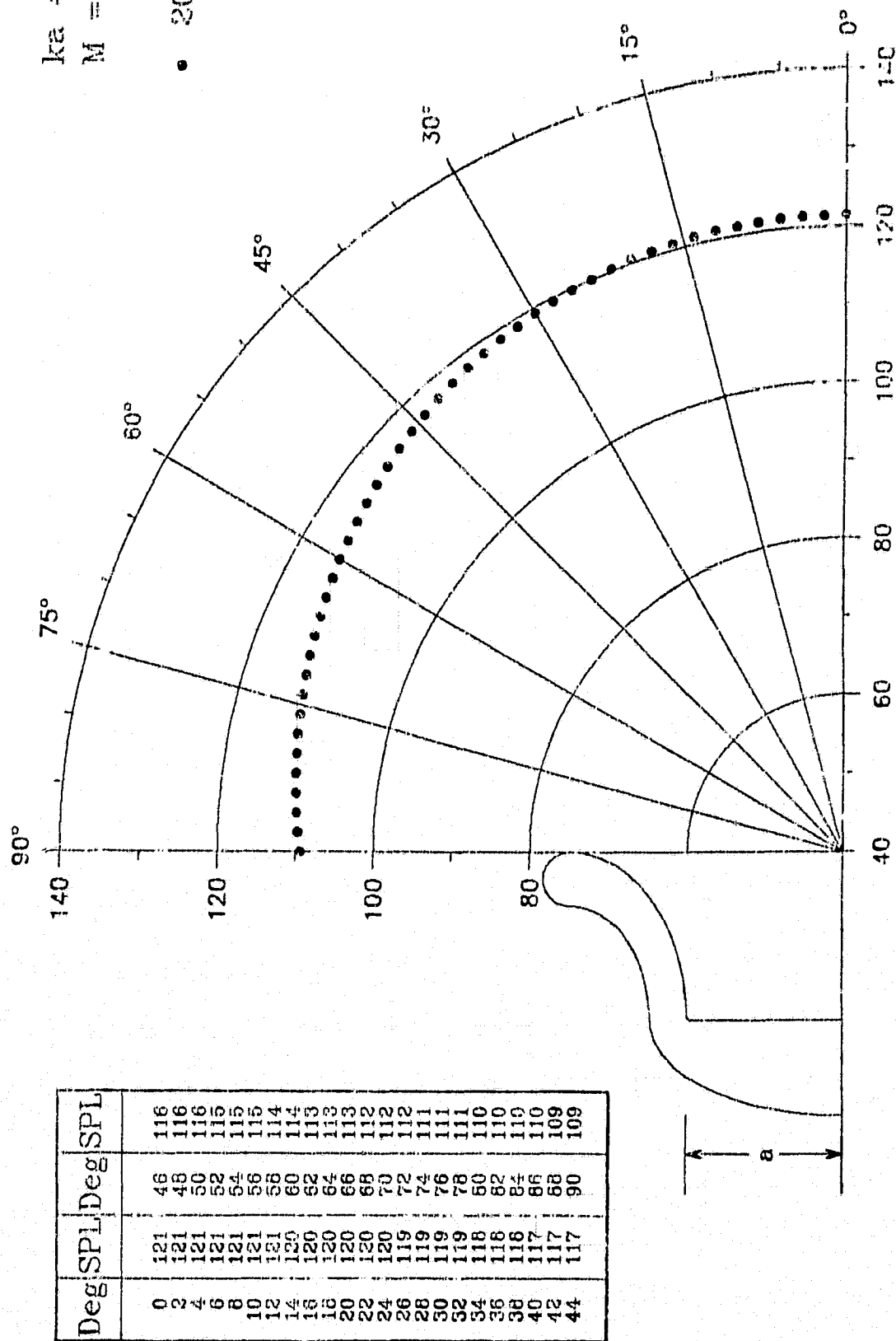


Fig. 2 SPL (dB)

LANCLEY BELLS

$f_{10} = 8.10$

$N = 10$

$\sigma = 20.50\%$

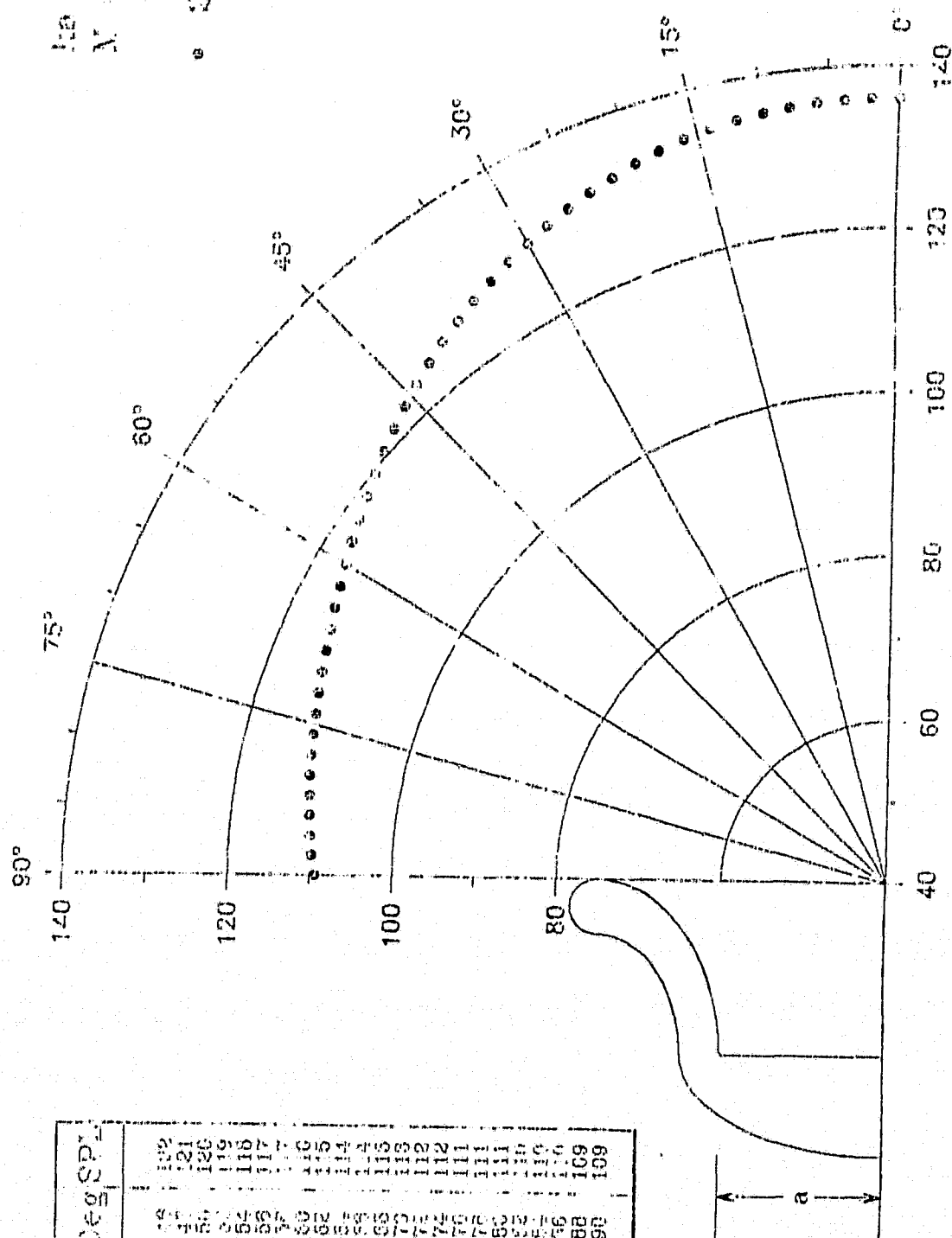


Fig. 3 SPL (dB)

Decibels SPL	Decibels SPL	Decibels SPL	Decibels SPL
0	10	110	120
2	12	112	122
4	14	114	124
6	16	116	126
8	18	118	128
10	20	120	130
12	22	122	132
14	24	124	134
16	26	126	136
18	28	128	138
20	30	130	140
22	32	132	142
24	34	134	144
26	36	136	146
28	38	138	148
30	40	140	150
32	42		
34	44		
36			
38			
40			
42			
44			

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LANGLEY BELLMOUTH

$ka = 1.91$

$M = 1$

$\sigma = 20.36\alpha$

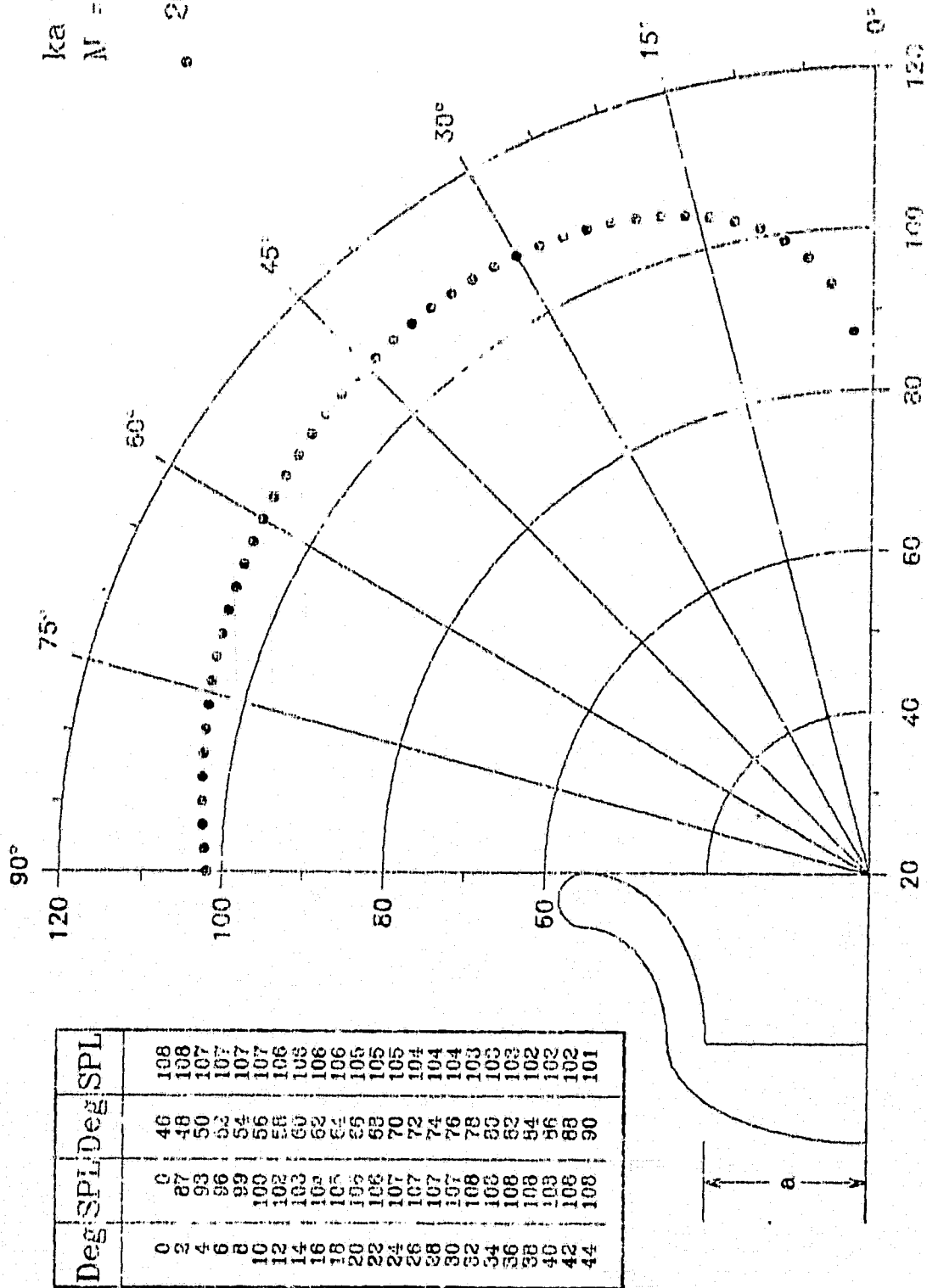


Fig. 4 SPL (dB)

LANGLEY BELLMOUTH

ka = 2.93
M = 1

20:63

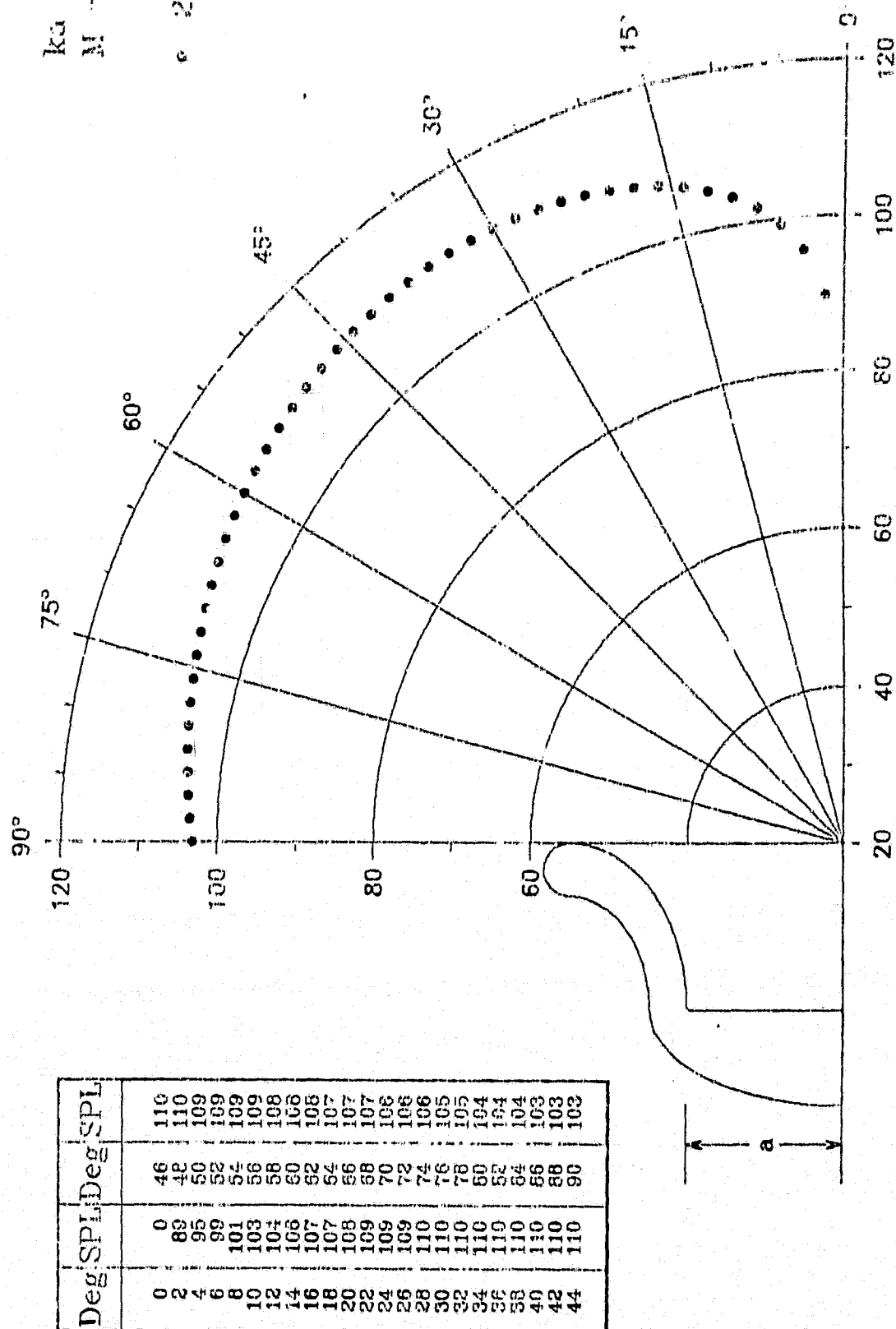


Fig. 5 SPL (dB)

LANCLEY BELLMOUTH

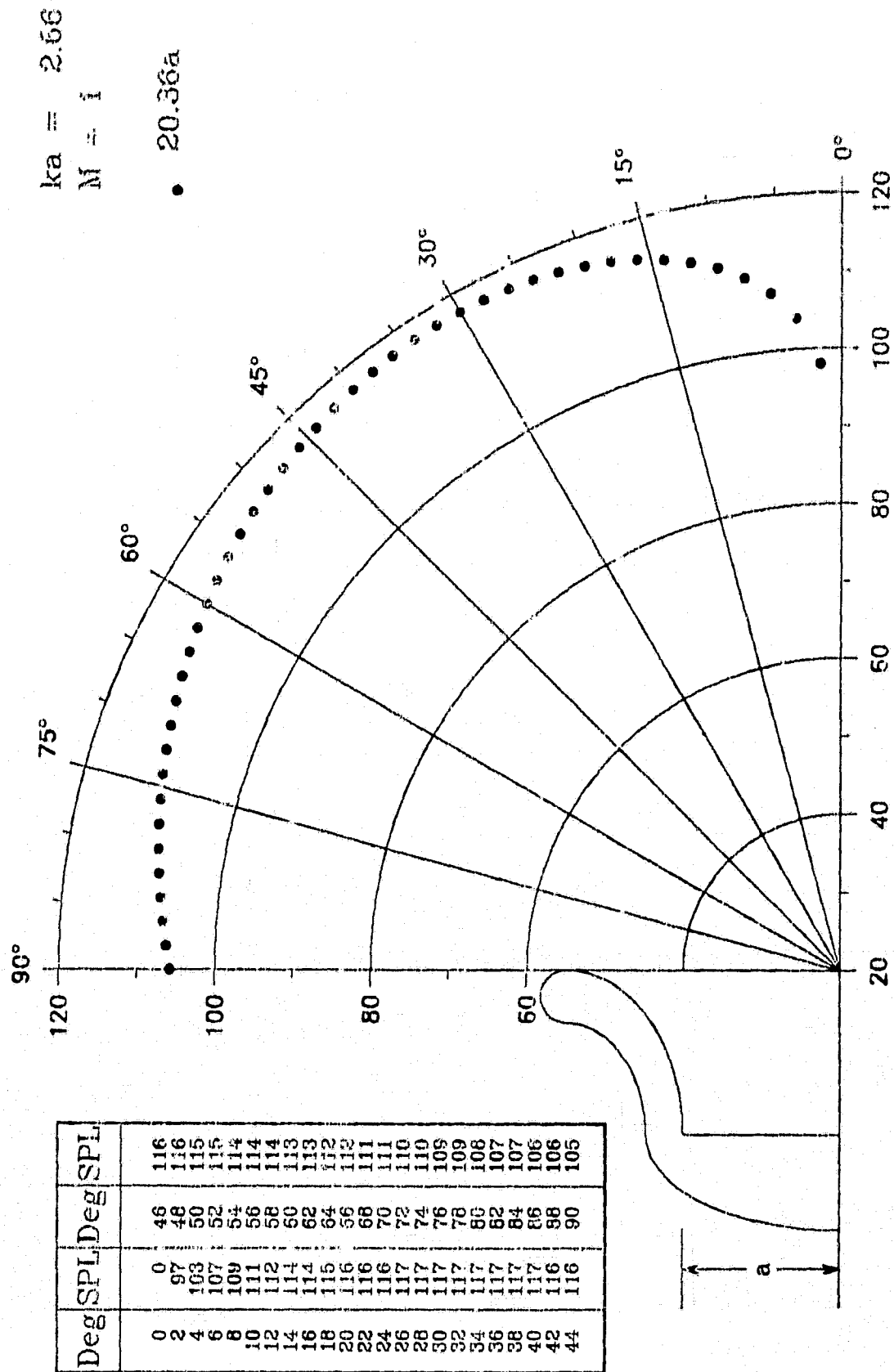


Fig. 6 SPL (dB)

LANGLEY BELLMOUTH

$ka = 3.76$

$M = 1$

• 20 36a

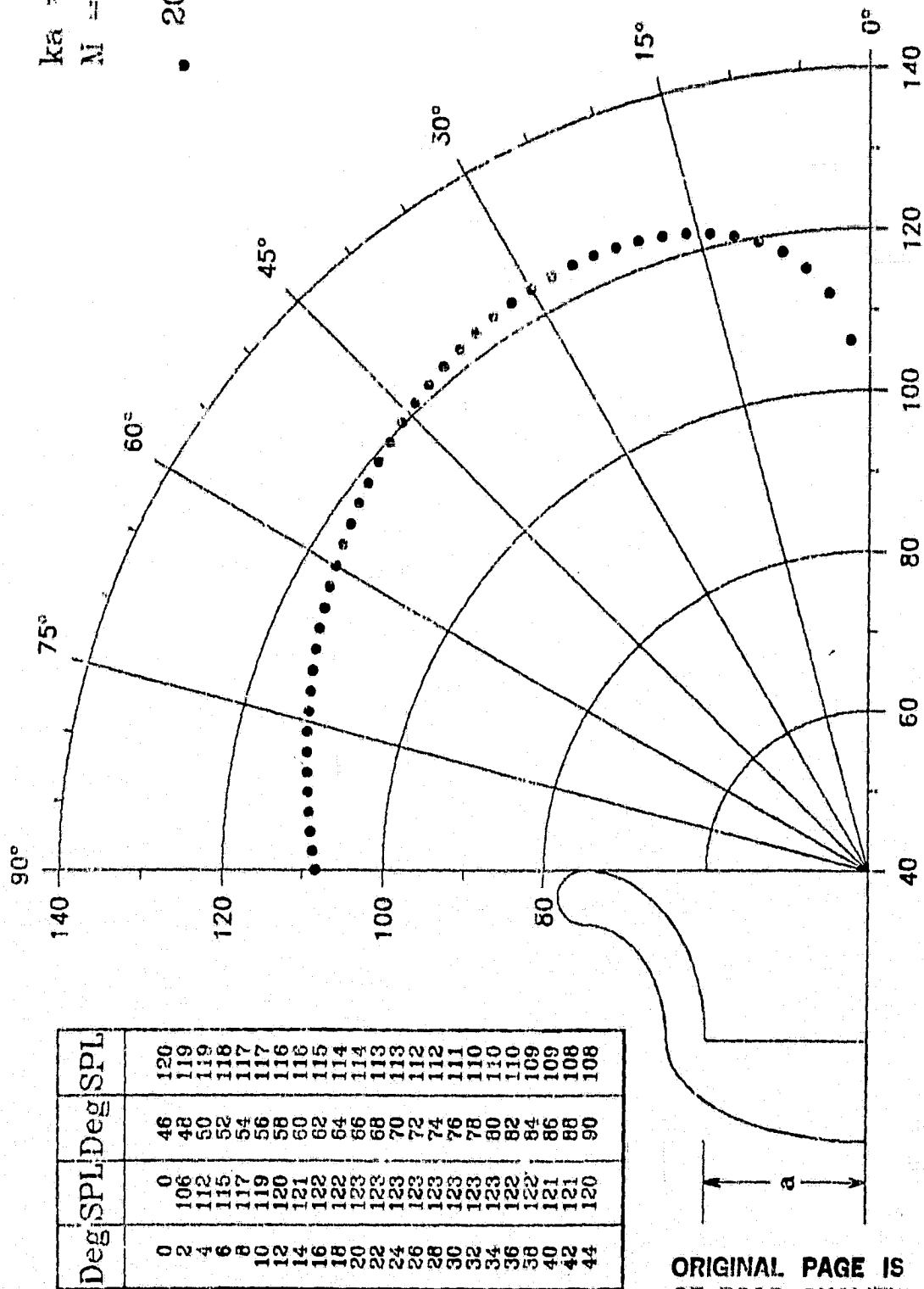


Fig. 7 SPL (dB)

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LANGLEY BELLMOUTH

$ka = 5.29$

$M = 1$

• 20.36a

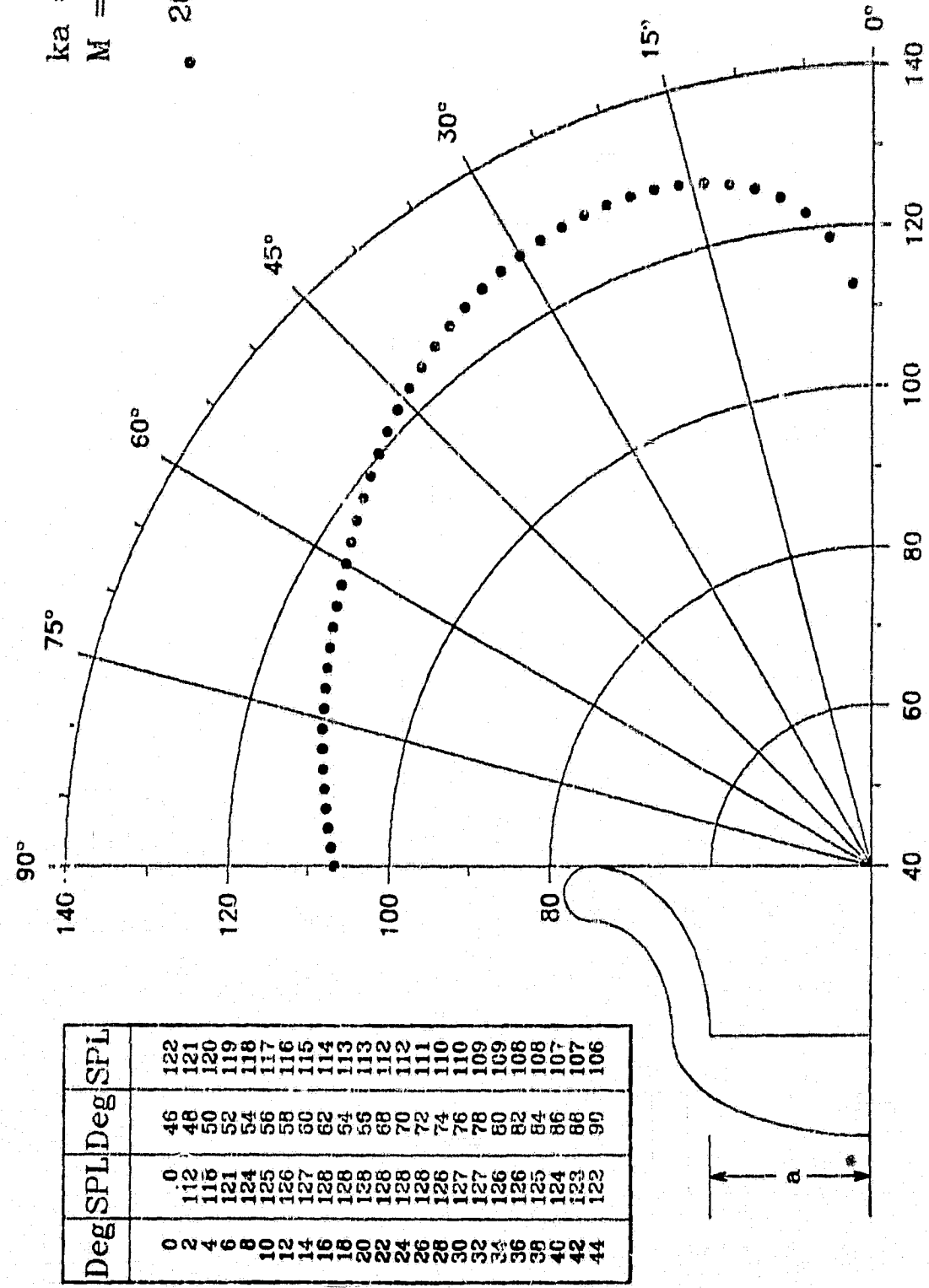


Fig. 8 SPL (dB)

LANGLEY BELLMOUTH

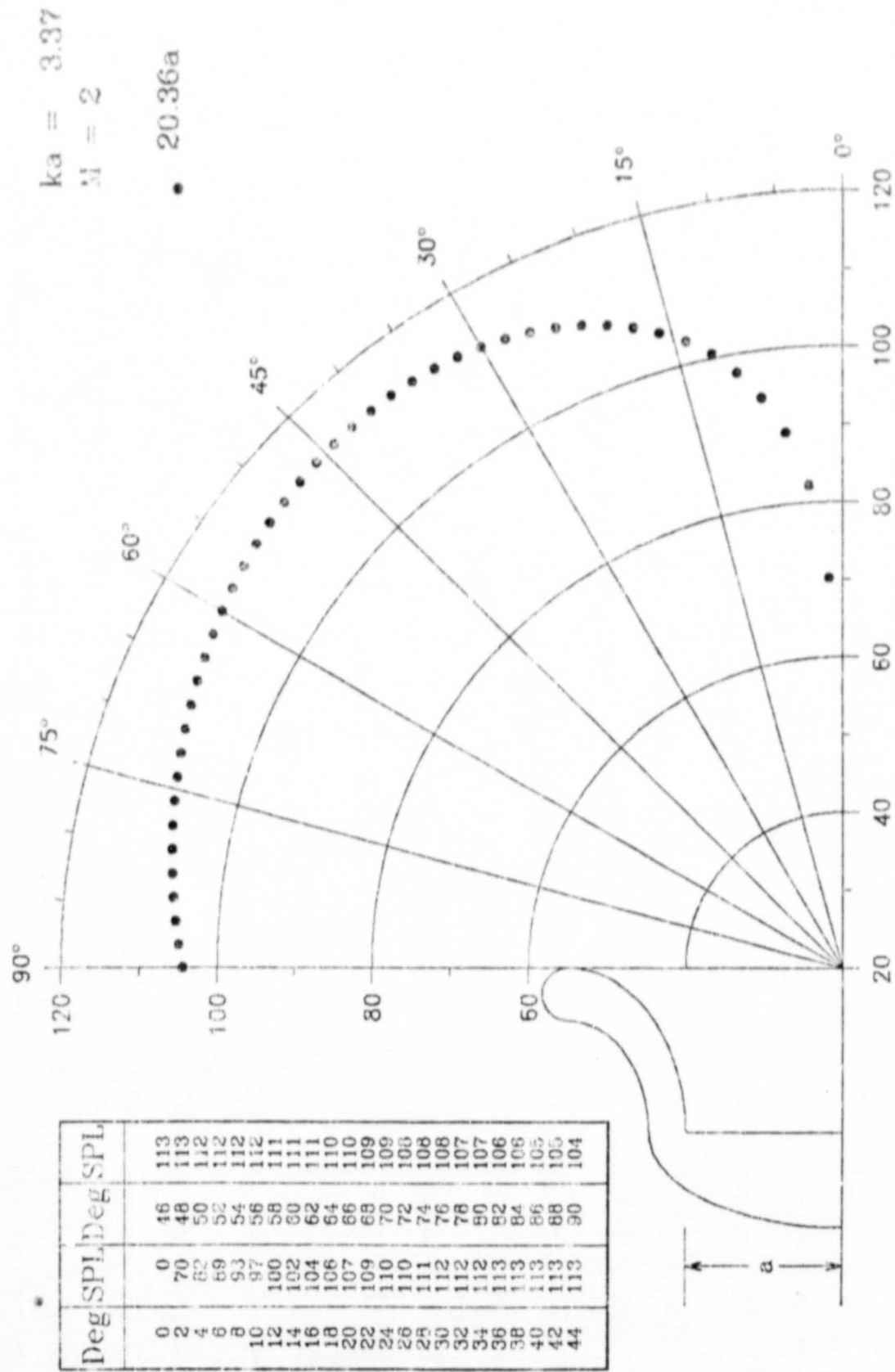


Fig. 9 SPL (dB)

LANGLEY BELLMOUTH

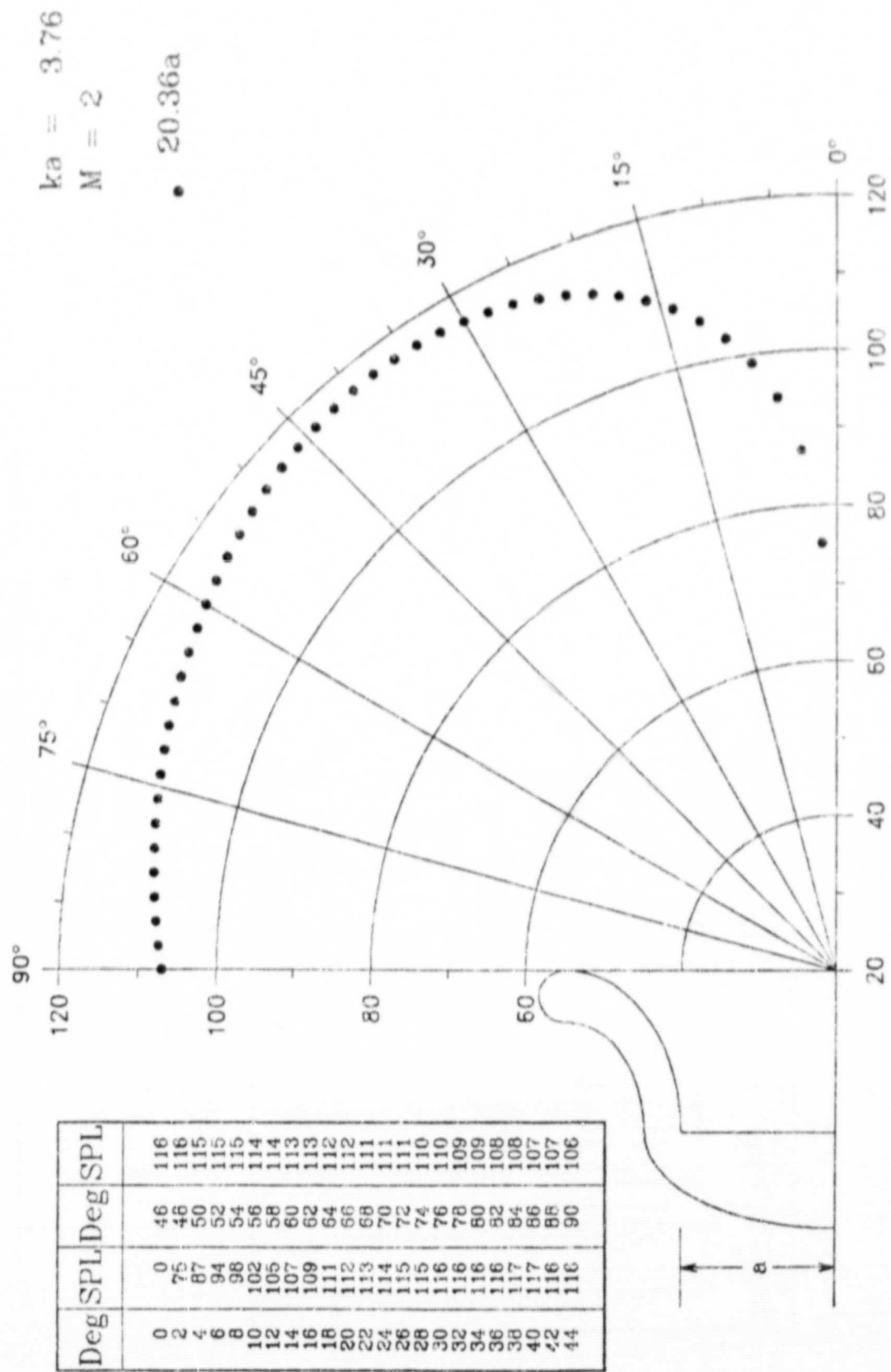


Fig. 10 SPL (dB)

LANCLEY BELLMOUTH

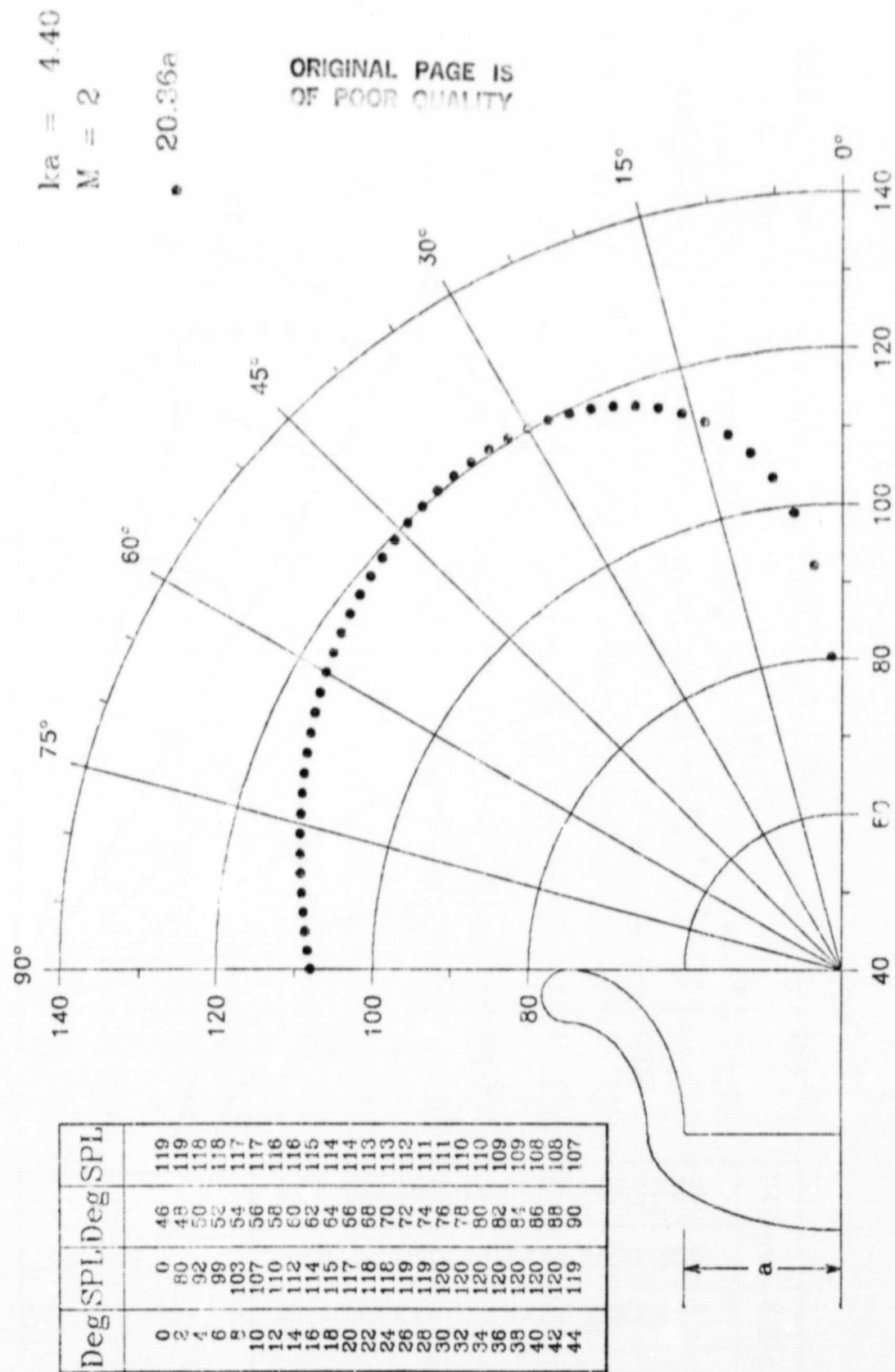


Fig. 11 SPL (dB)

LANGLEY BELLMOUTH

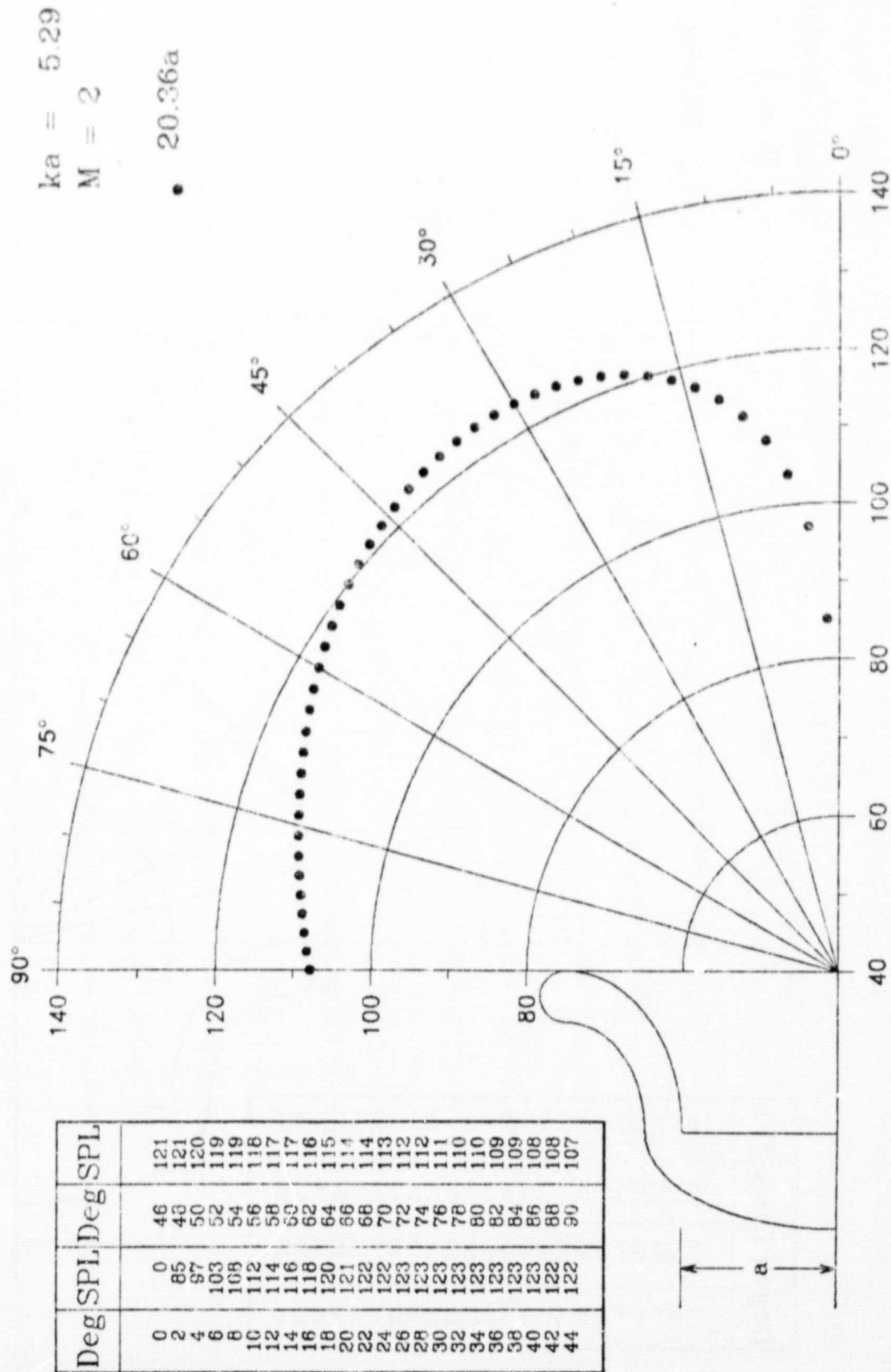


Fig. 12 SPL (dB)

LANGLEY BELLMOUTH

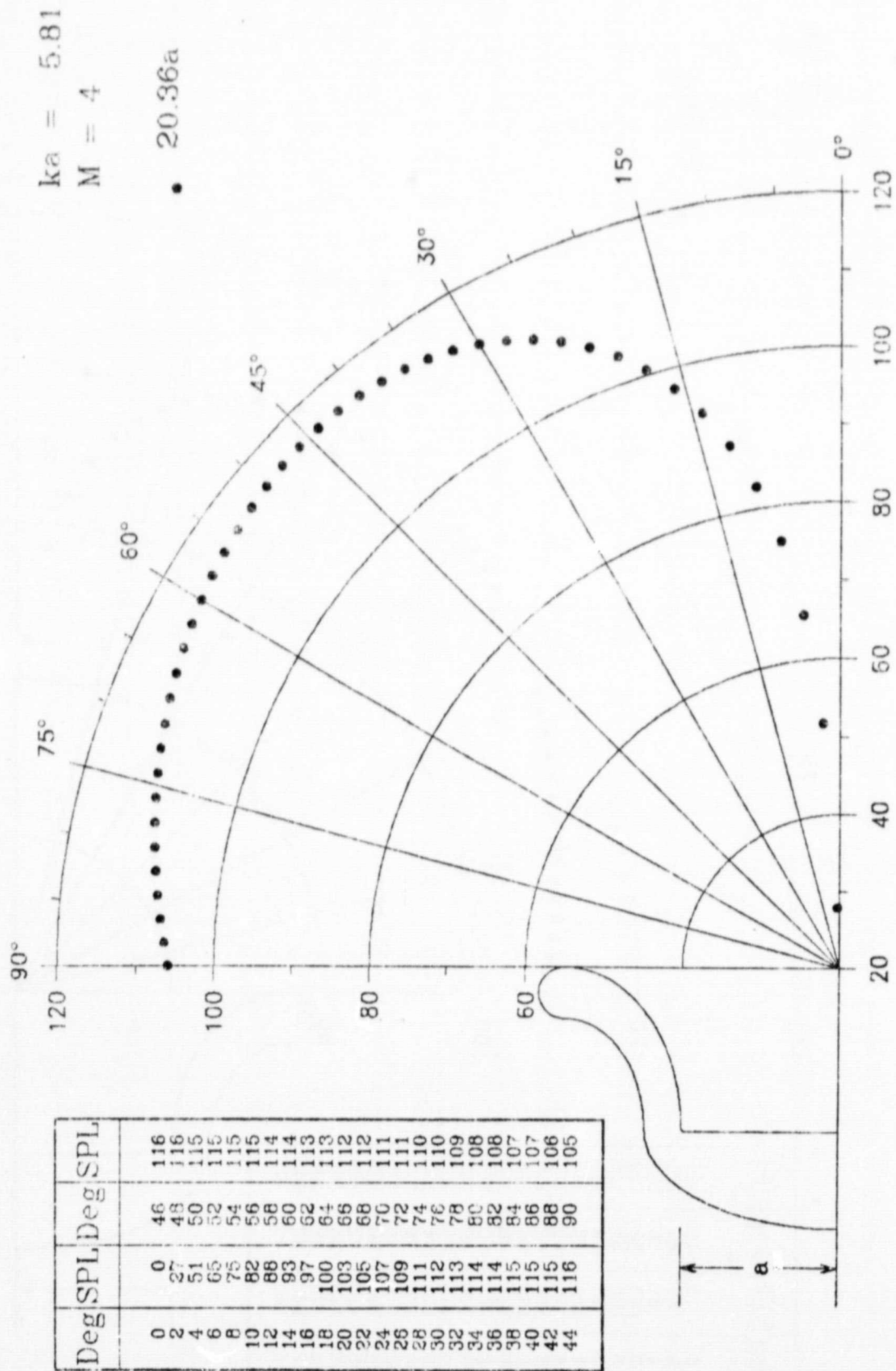


Fig. 13 SPL (dB)

LANGLEY BELLMOUTH

$ka = 11.14$
 $M = 6$
 $\bullet 20.36a$

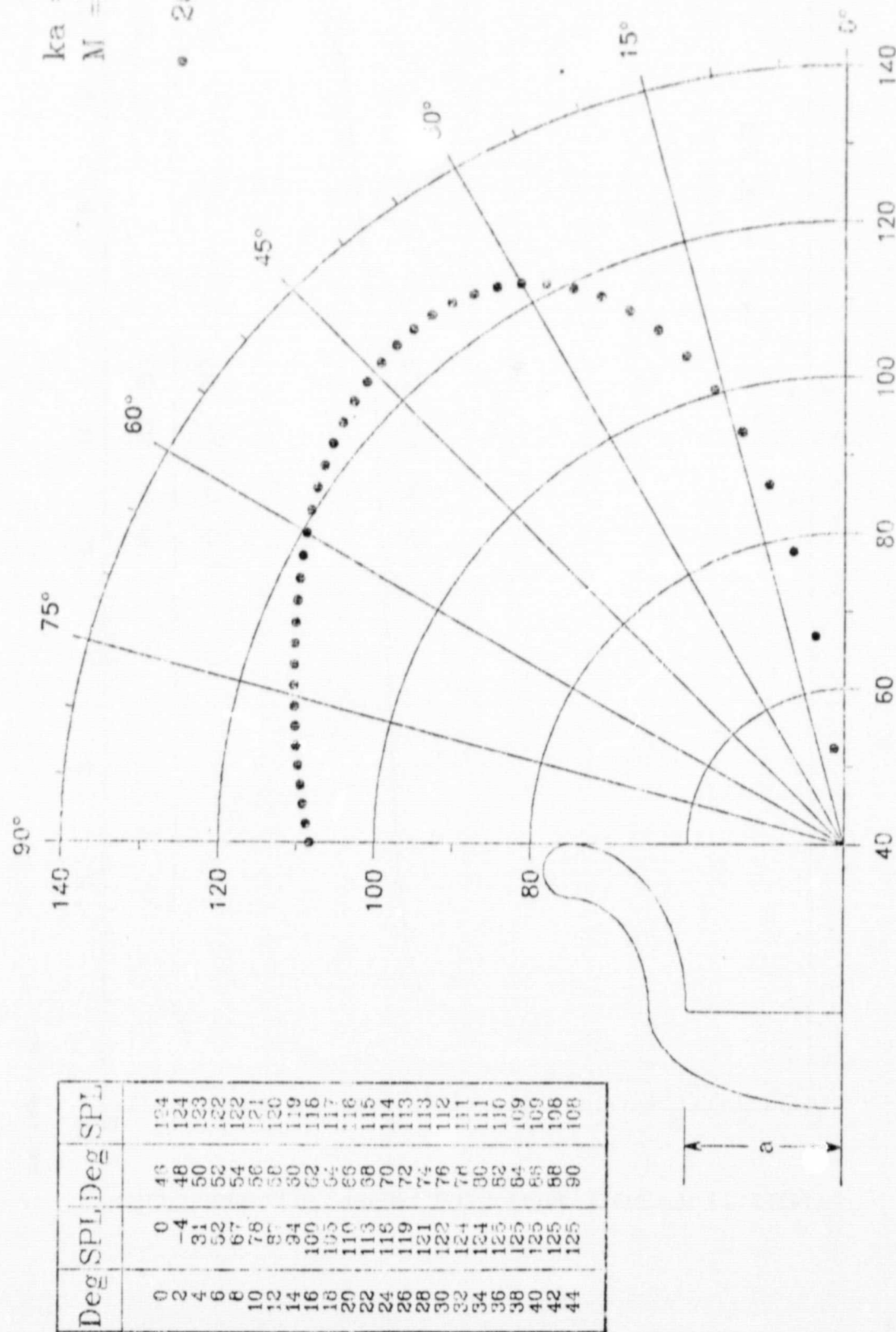
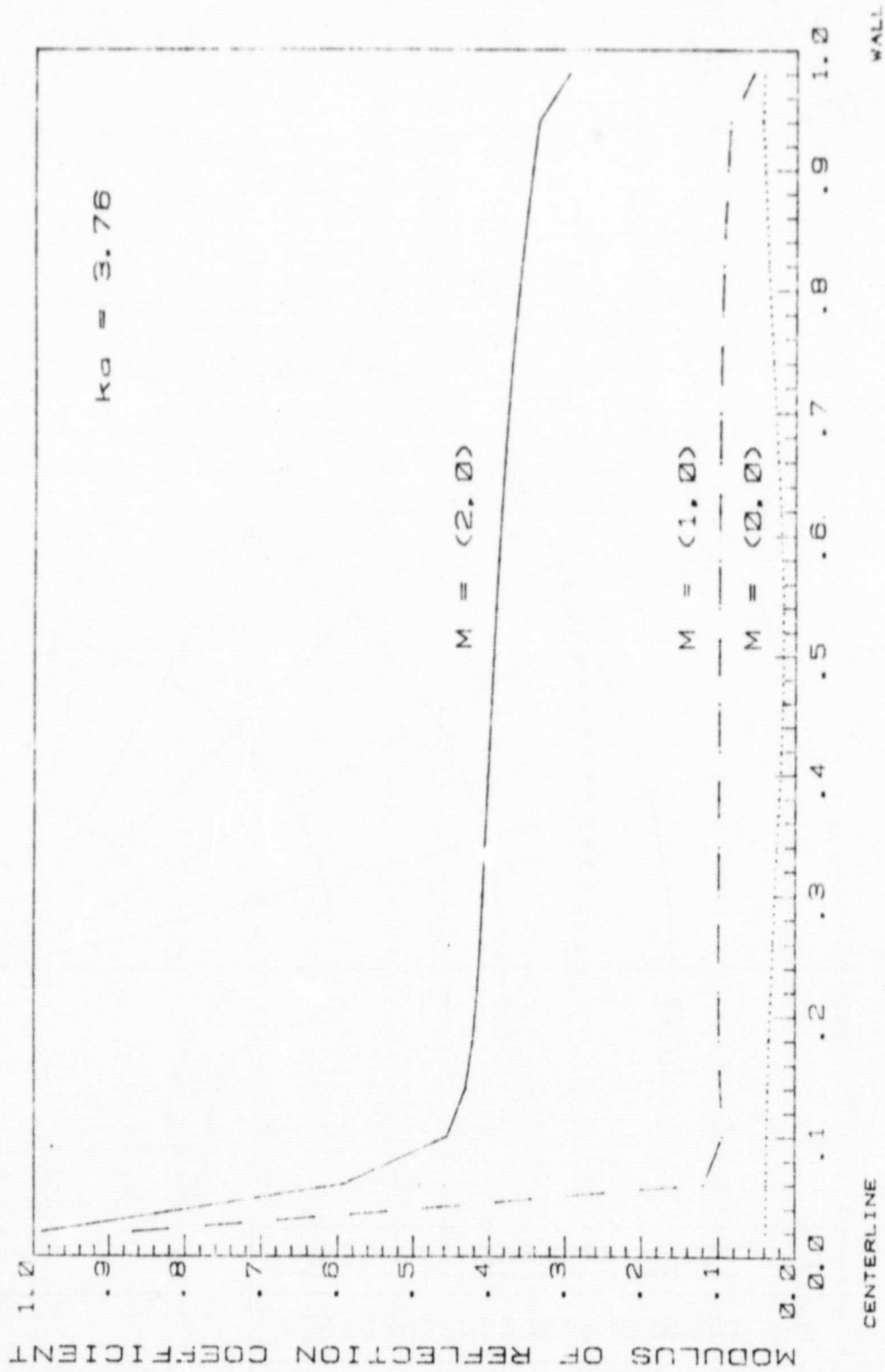
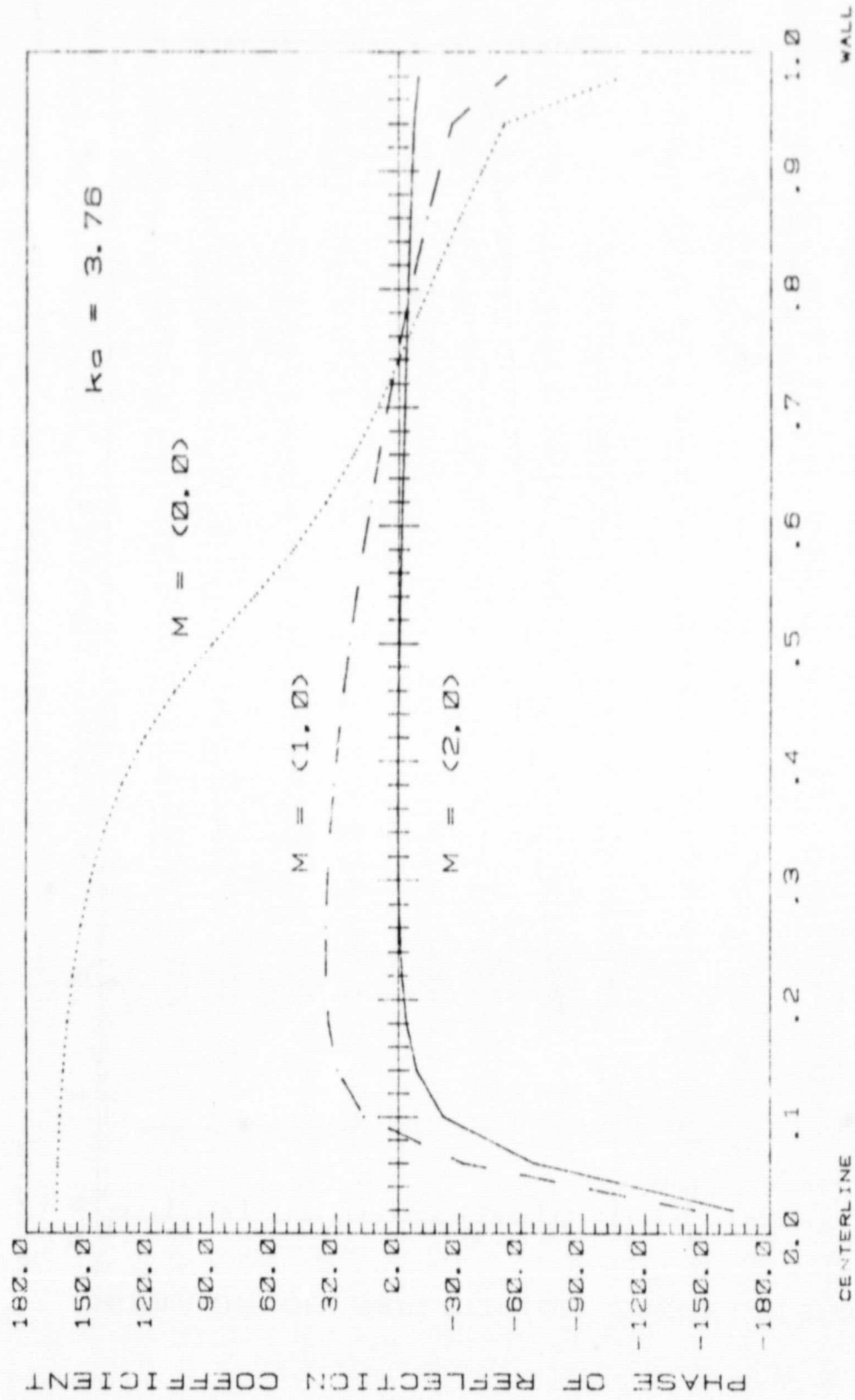


Fig. 14 SPL (dB)



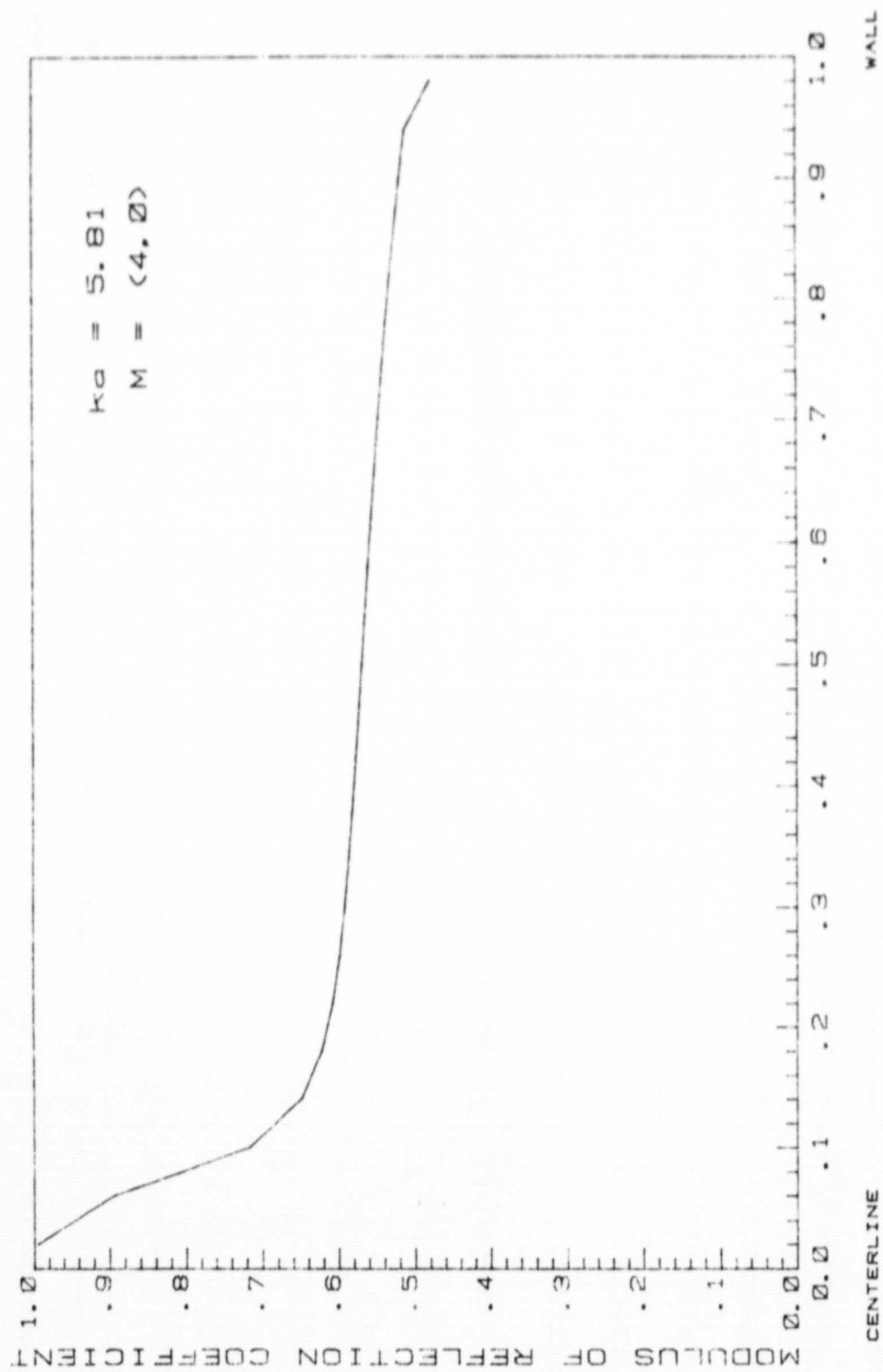
LANGLEY BELLMOUTH (Exit Plane)

Fig. 15



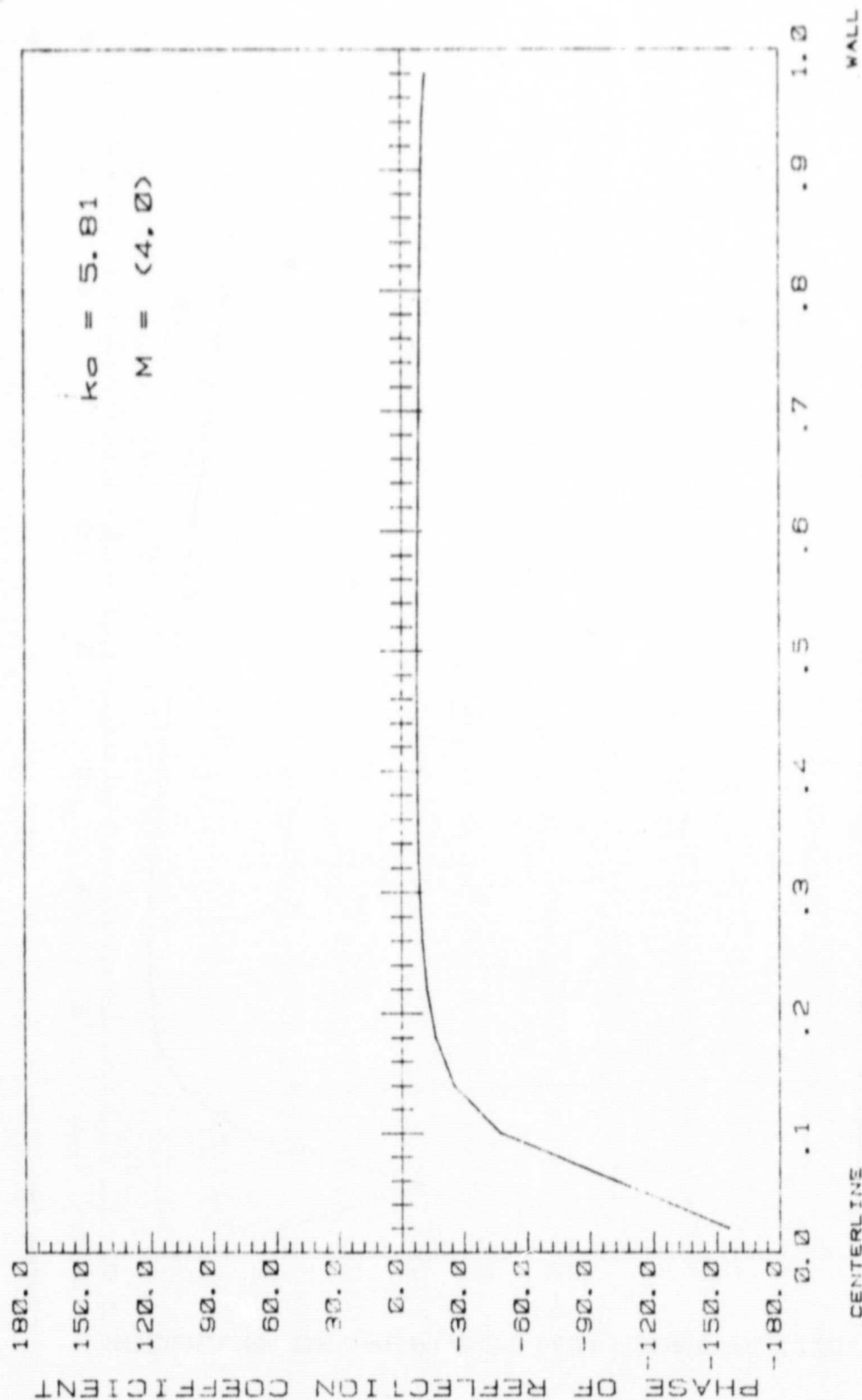
LANGLEY BELLMOUTH (Exit Plane)

Fig. 16



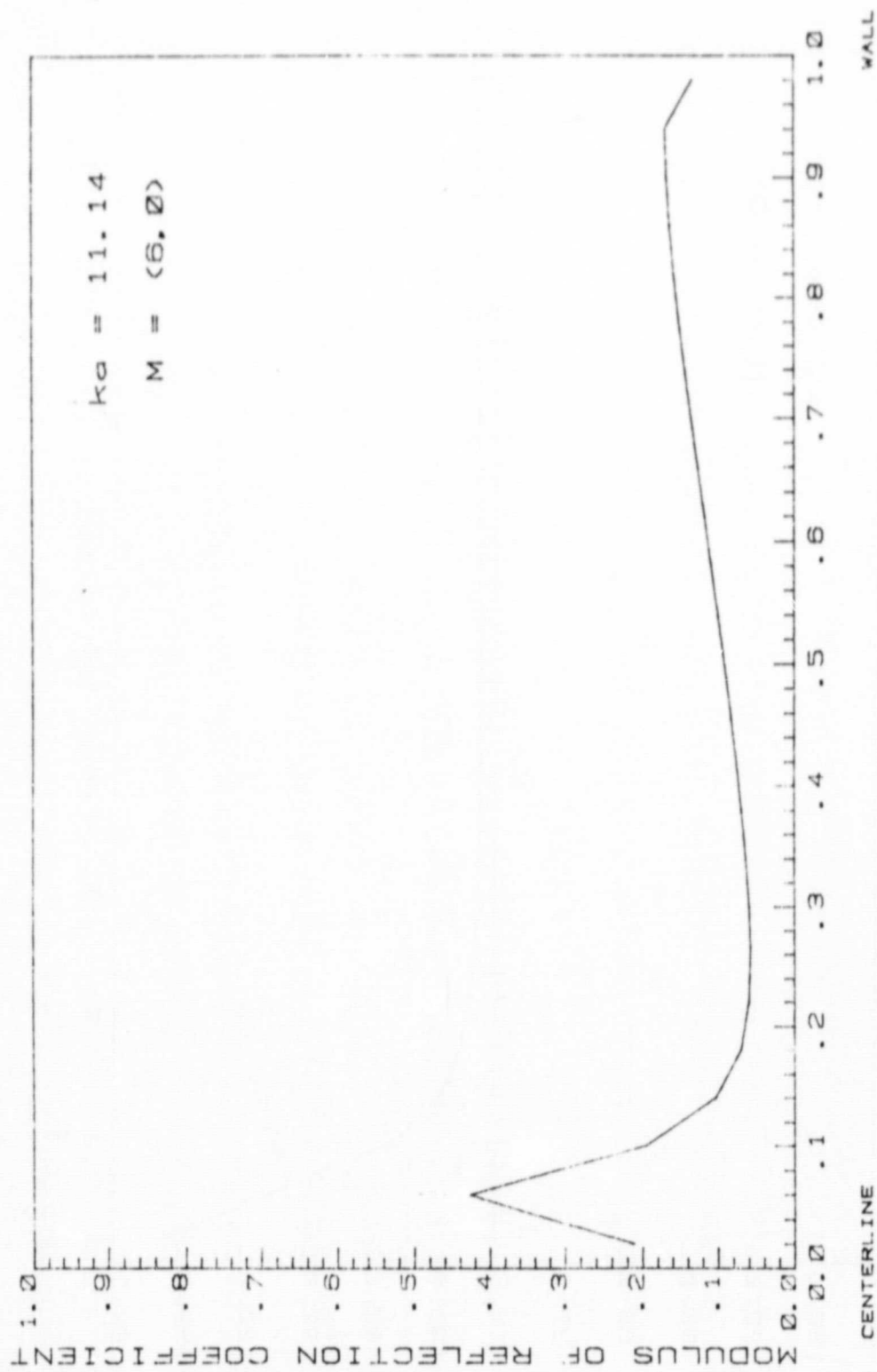
LANGLEY BELLMOUTH (Exit Plane)

Fig. 17



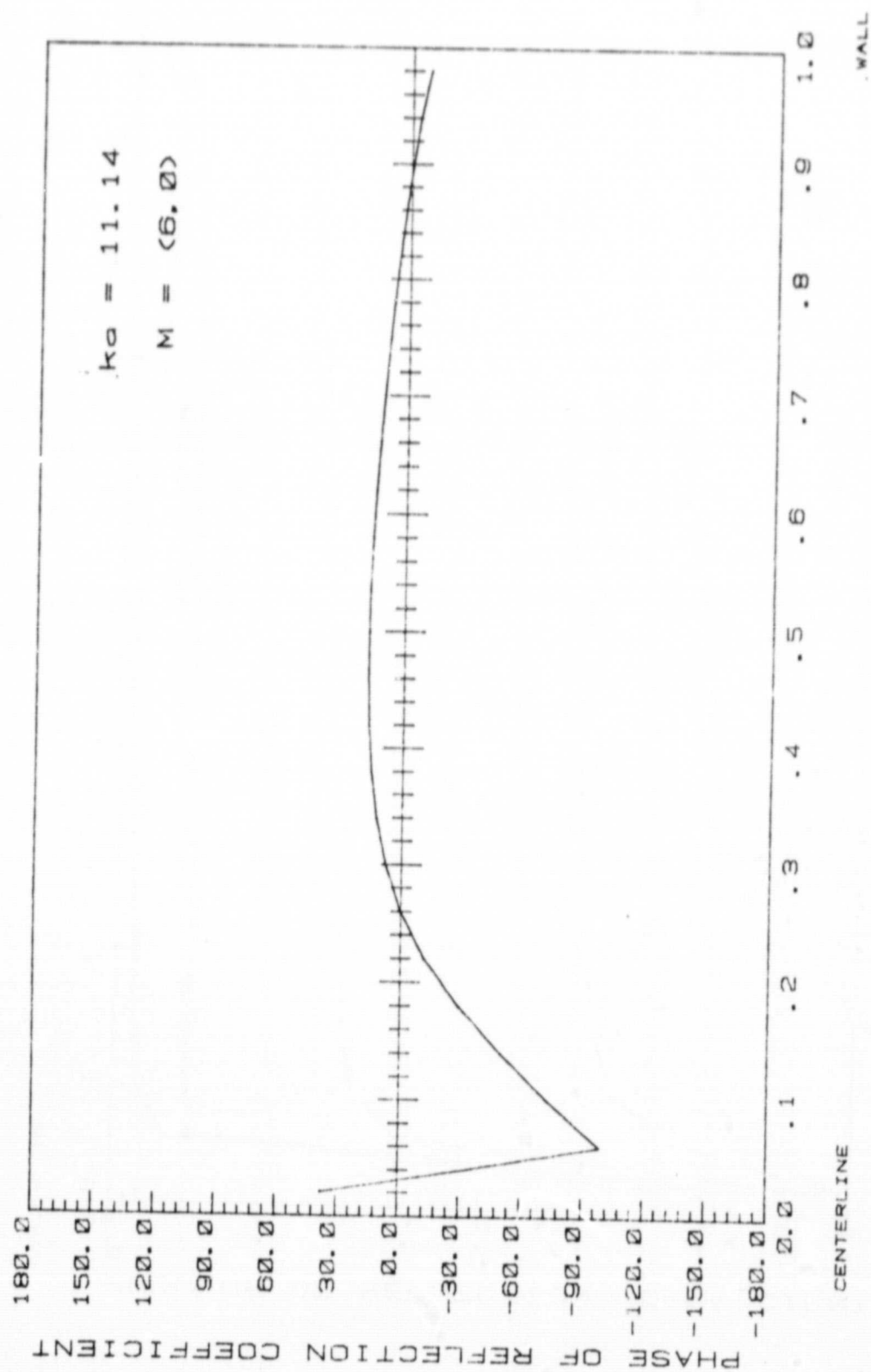
LANGLEY BELLMOUTH (Exit Plane)

Fig. 18



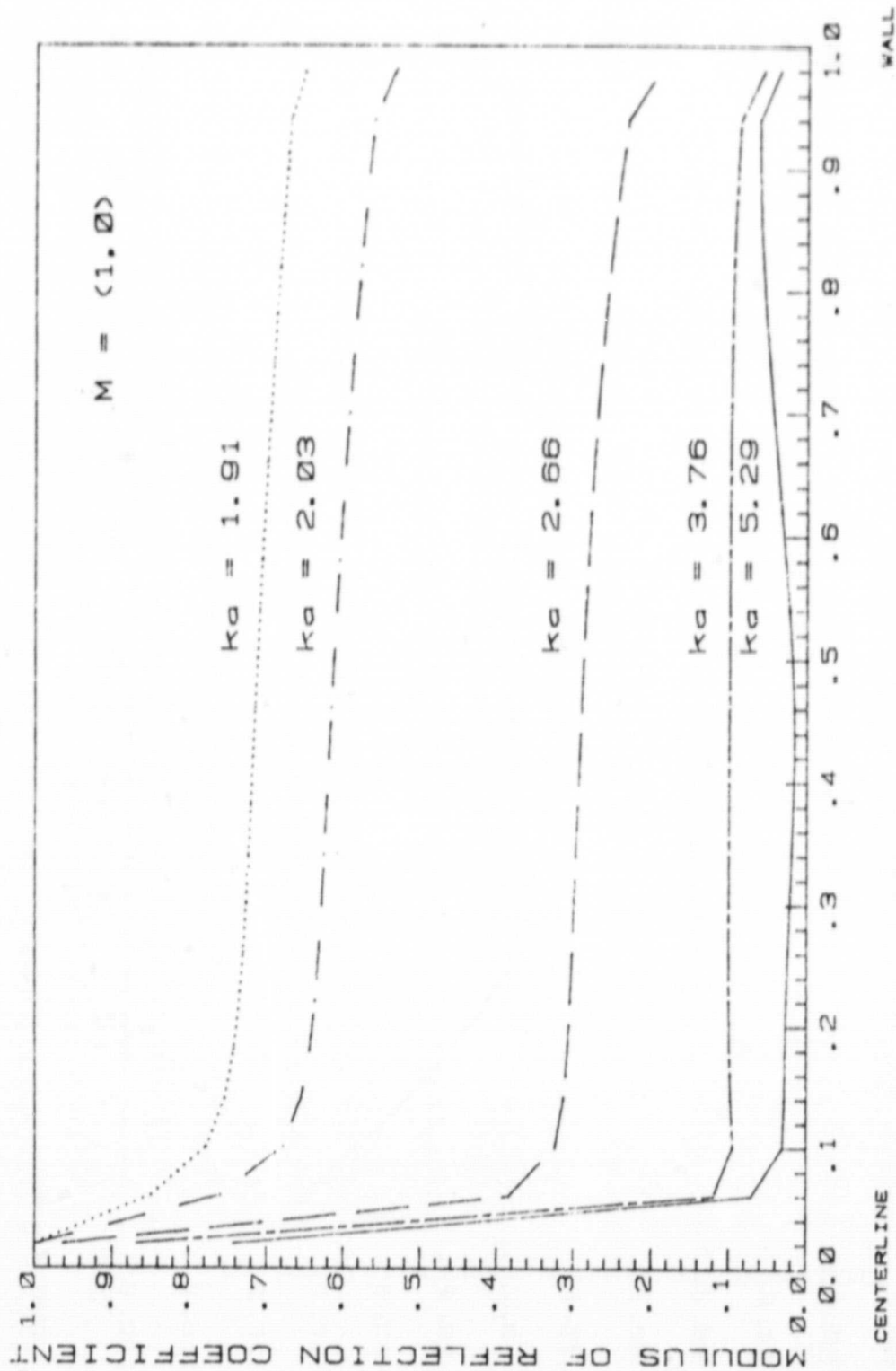
LANGLEY BELLMOUTH (Exit Plane)

Fig. 19



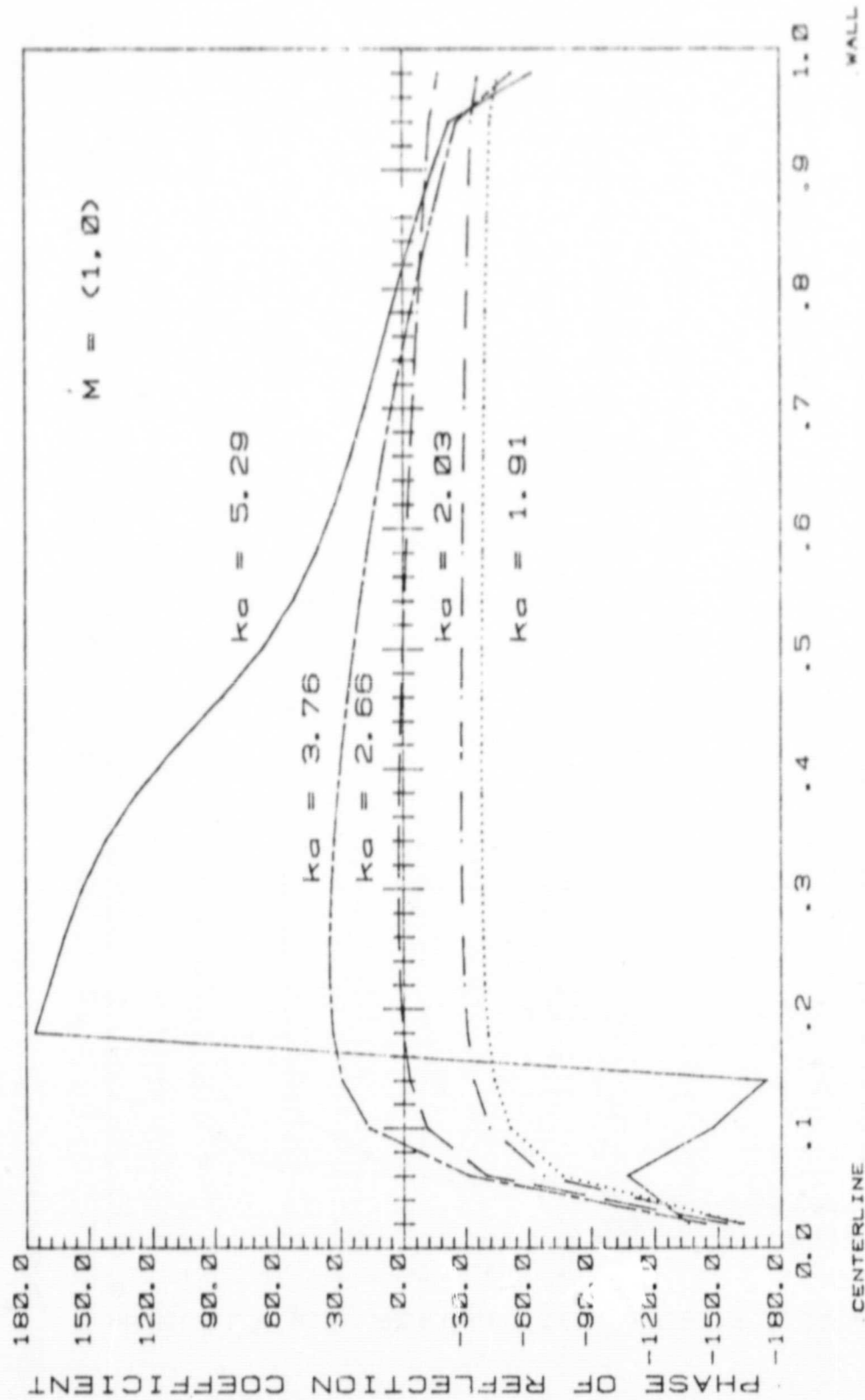
LANGLEY BELLMOUTH (Exit Plane)

Fig. 20



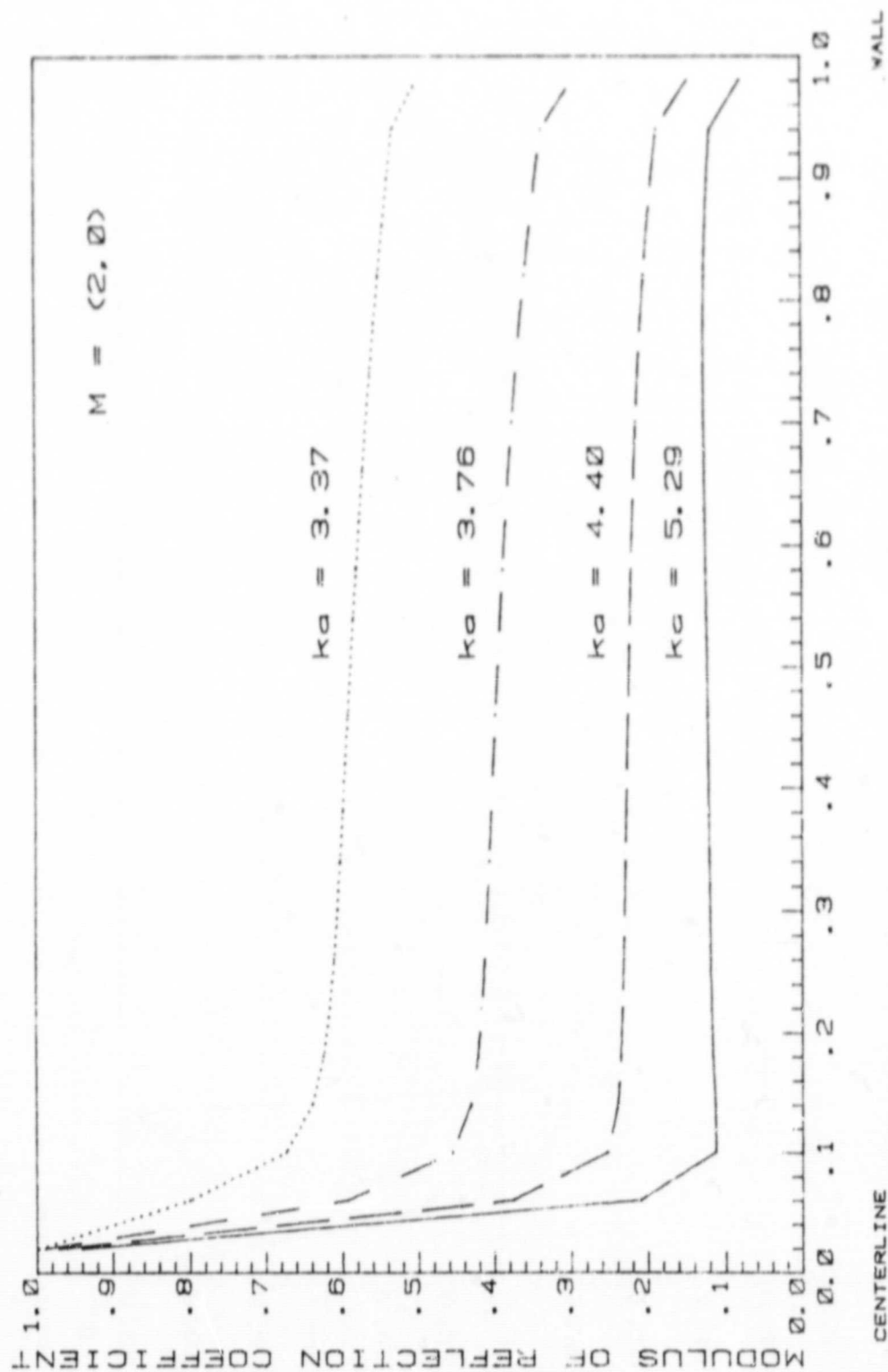
LANGLEY BELLMOUTH (Exit Plane)

Fig. 21



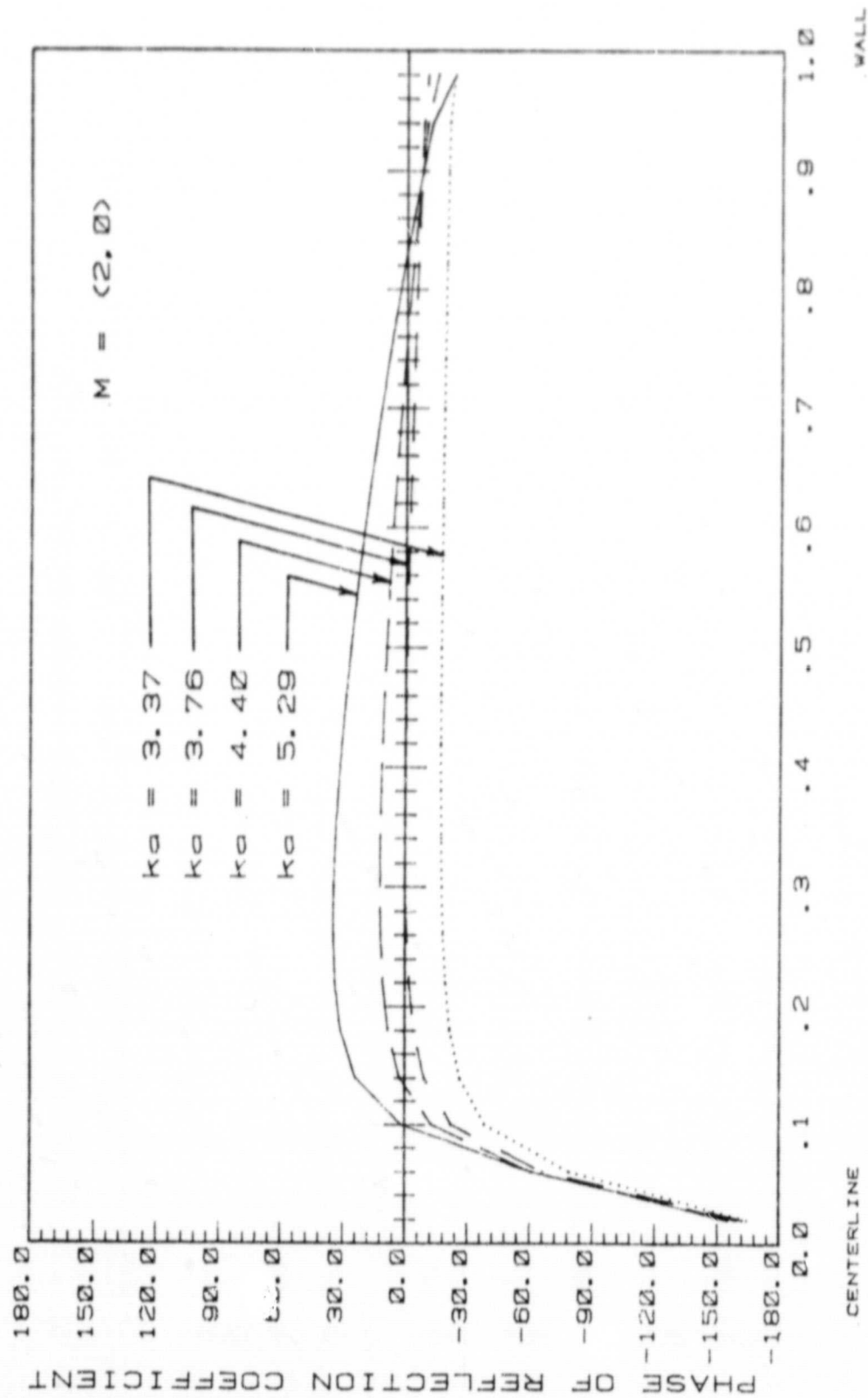
LANGLEY BELLMOUTH (Exit Plane)

Fig. 22

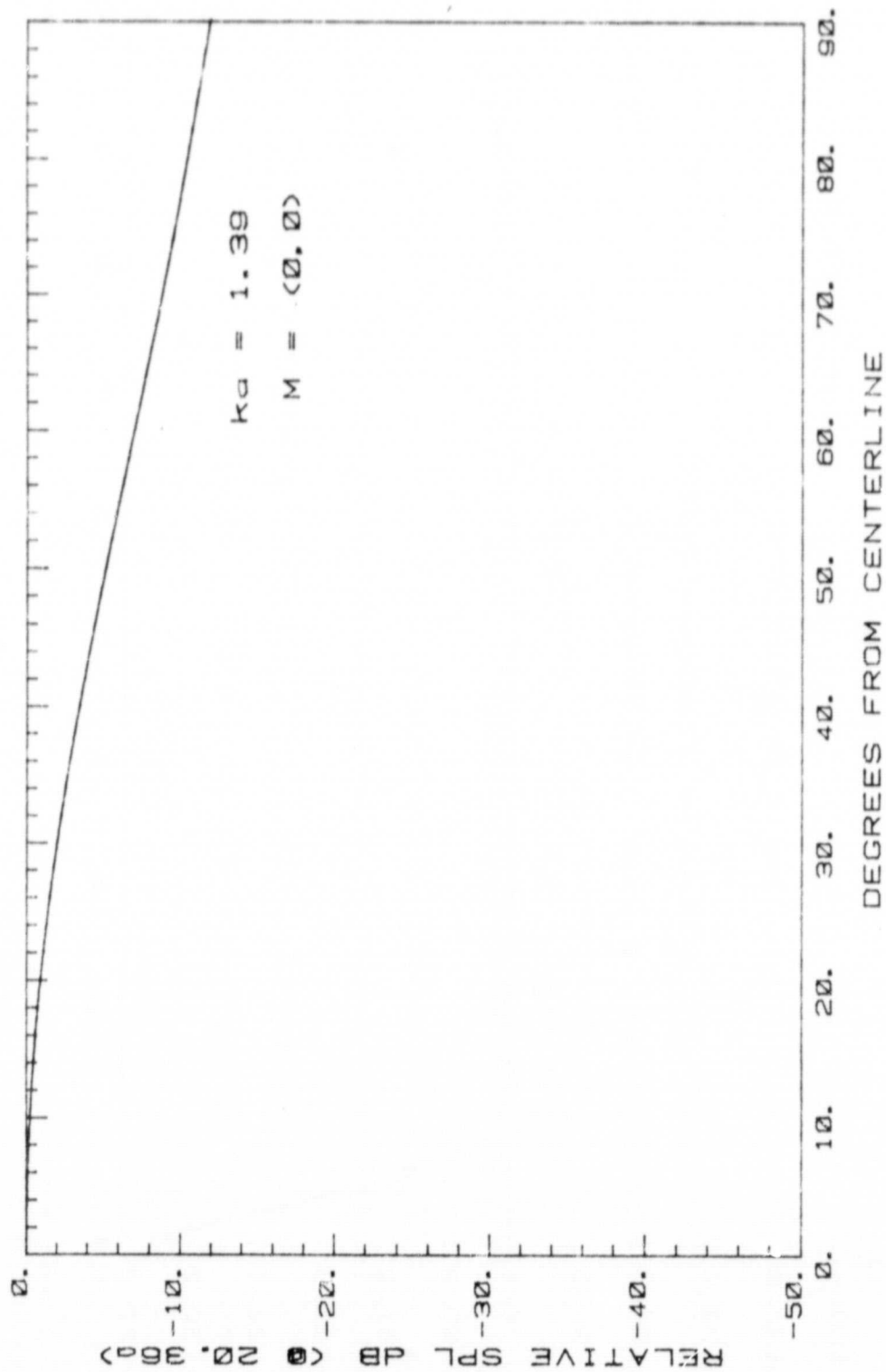


LANGLEY BELLMOUTH (Exit Plane)

Fig. 23

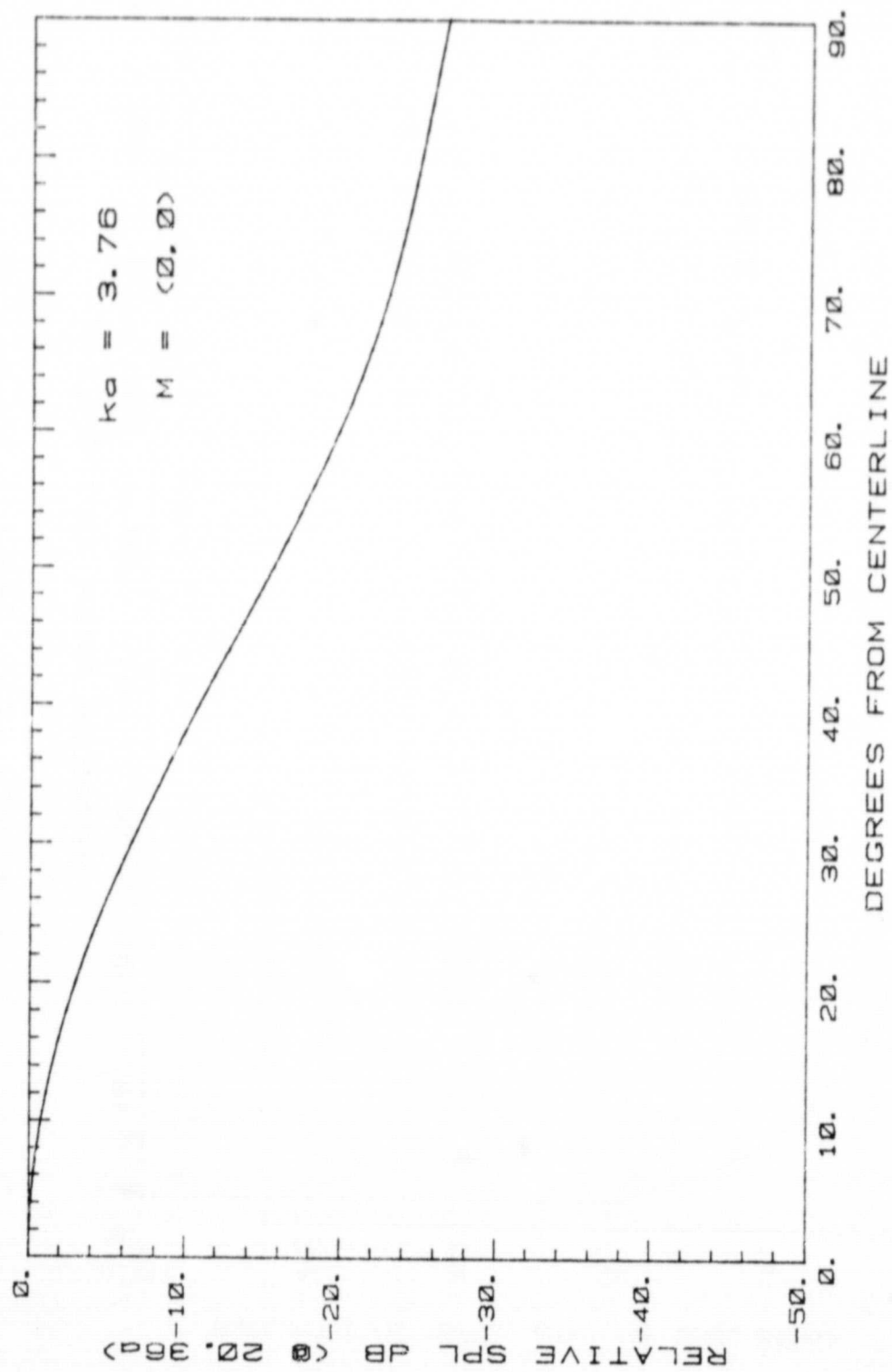


LANGLEY BELLMOUTH (Exit Plane)



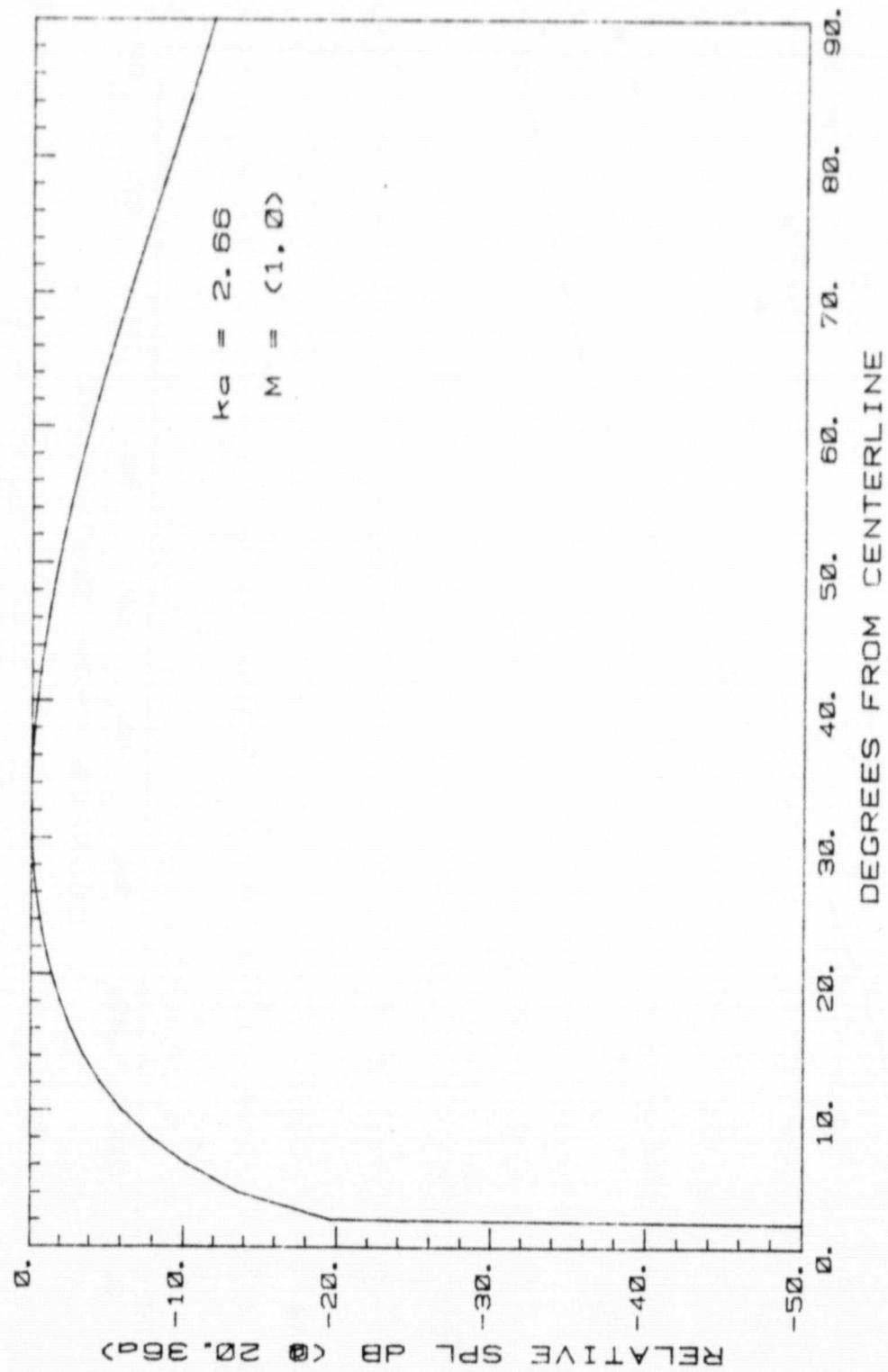
LANGLEY BELLMOUTH

Fig. 25



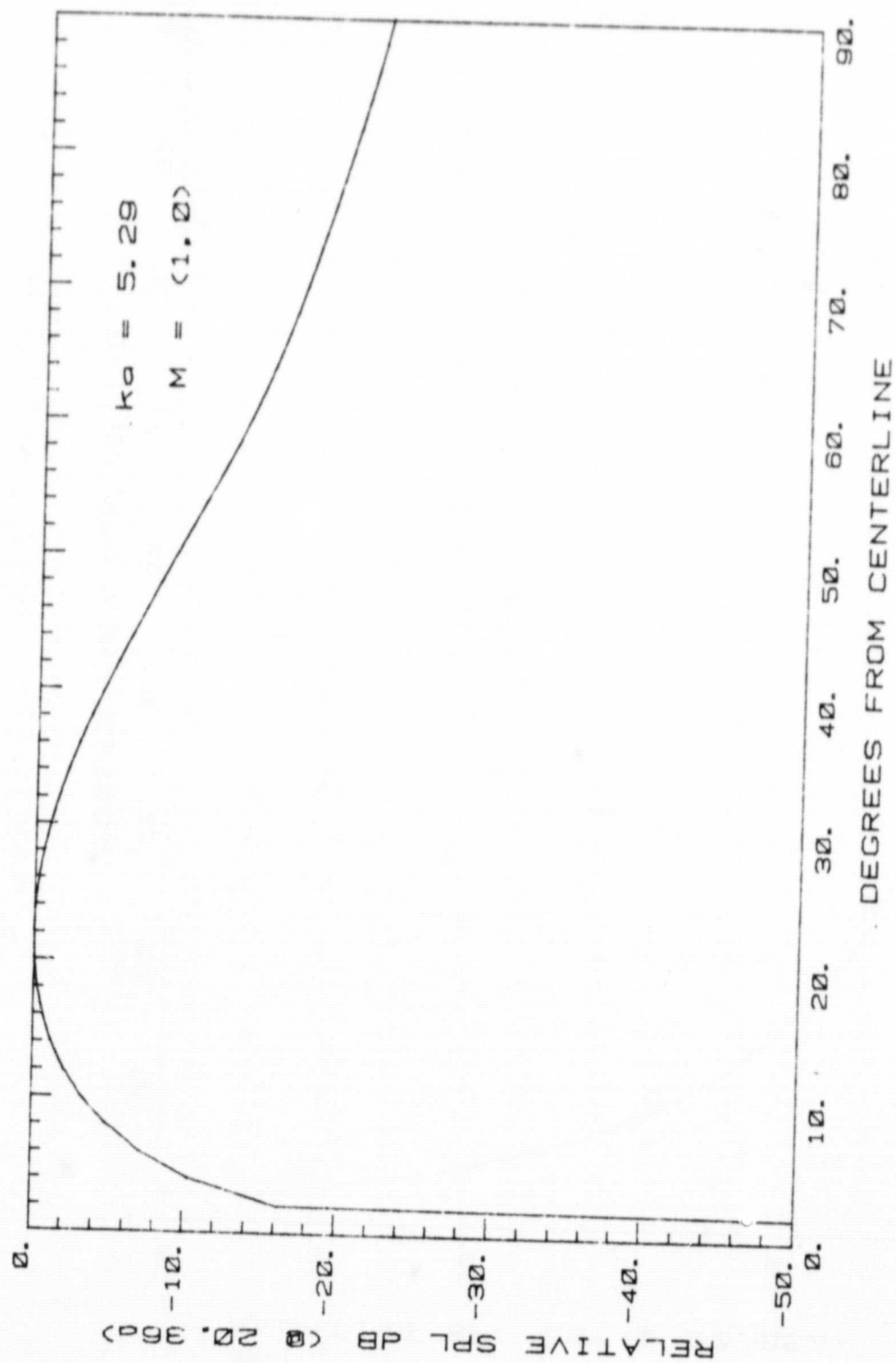
LANGLEY BELLMOUTH

Fig. 26



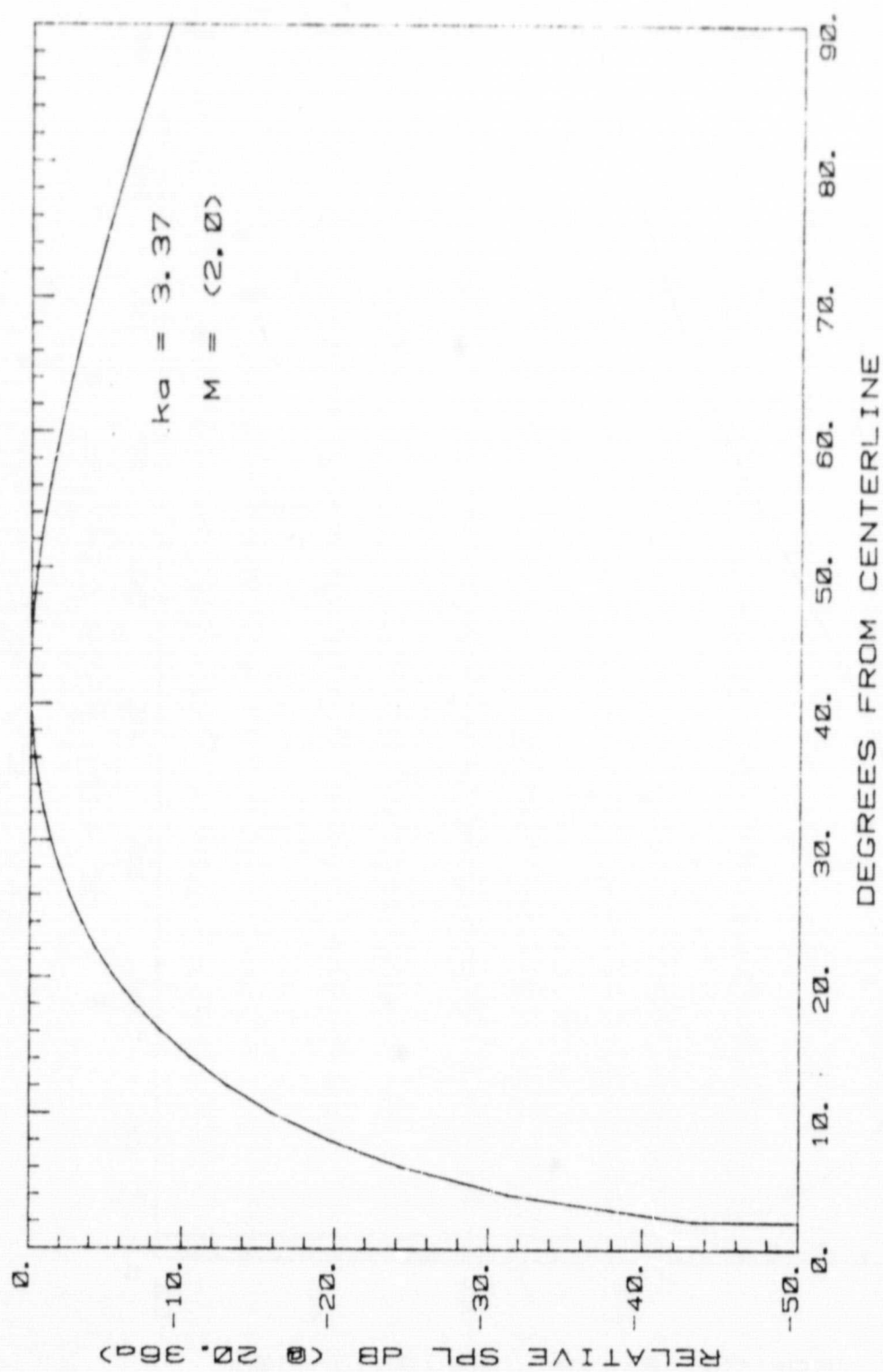
LANGLEY BELLMOUTH

Fig. 27



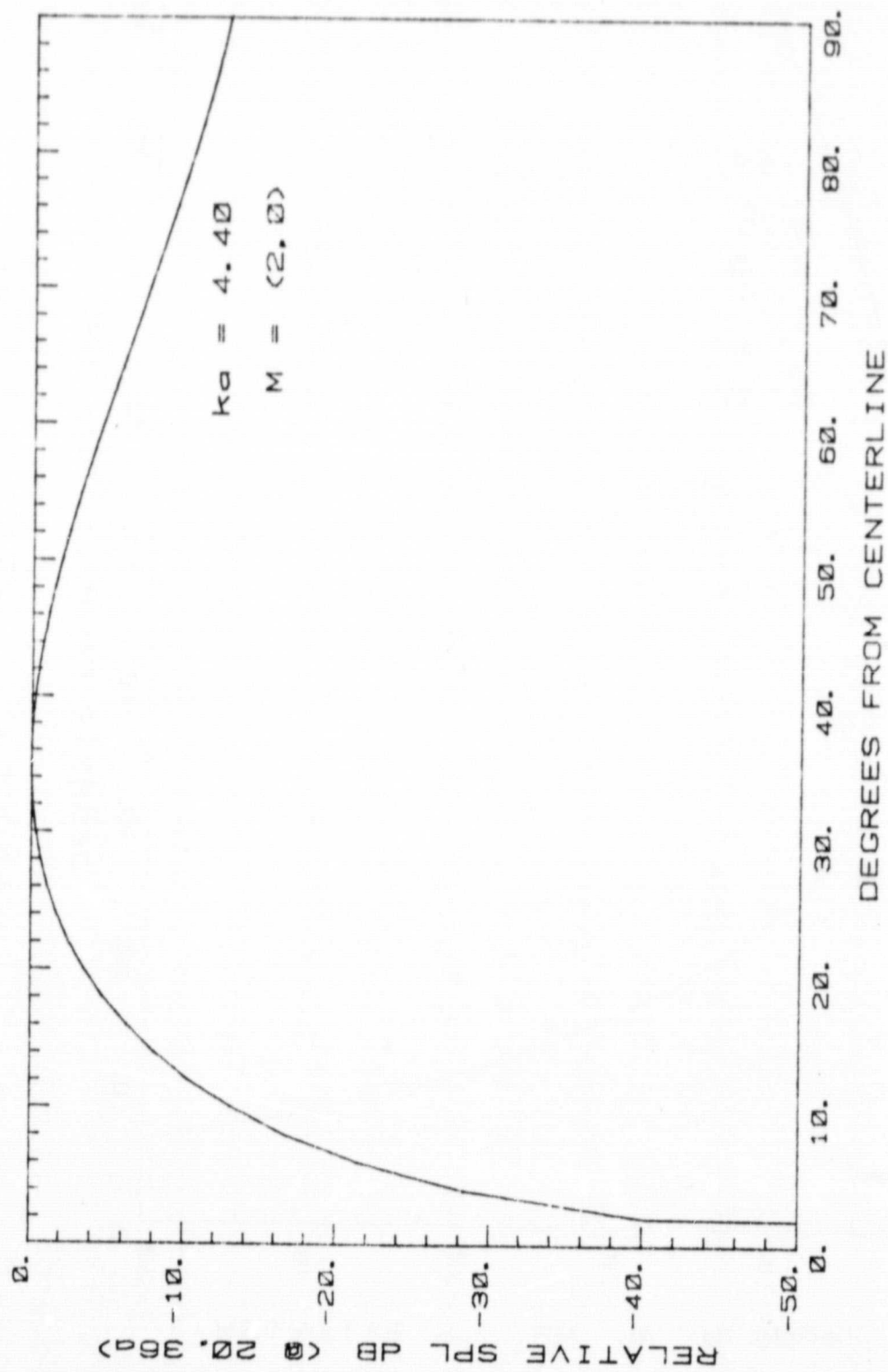
LANGLEY BELLMOUTH

Fig. 28



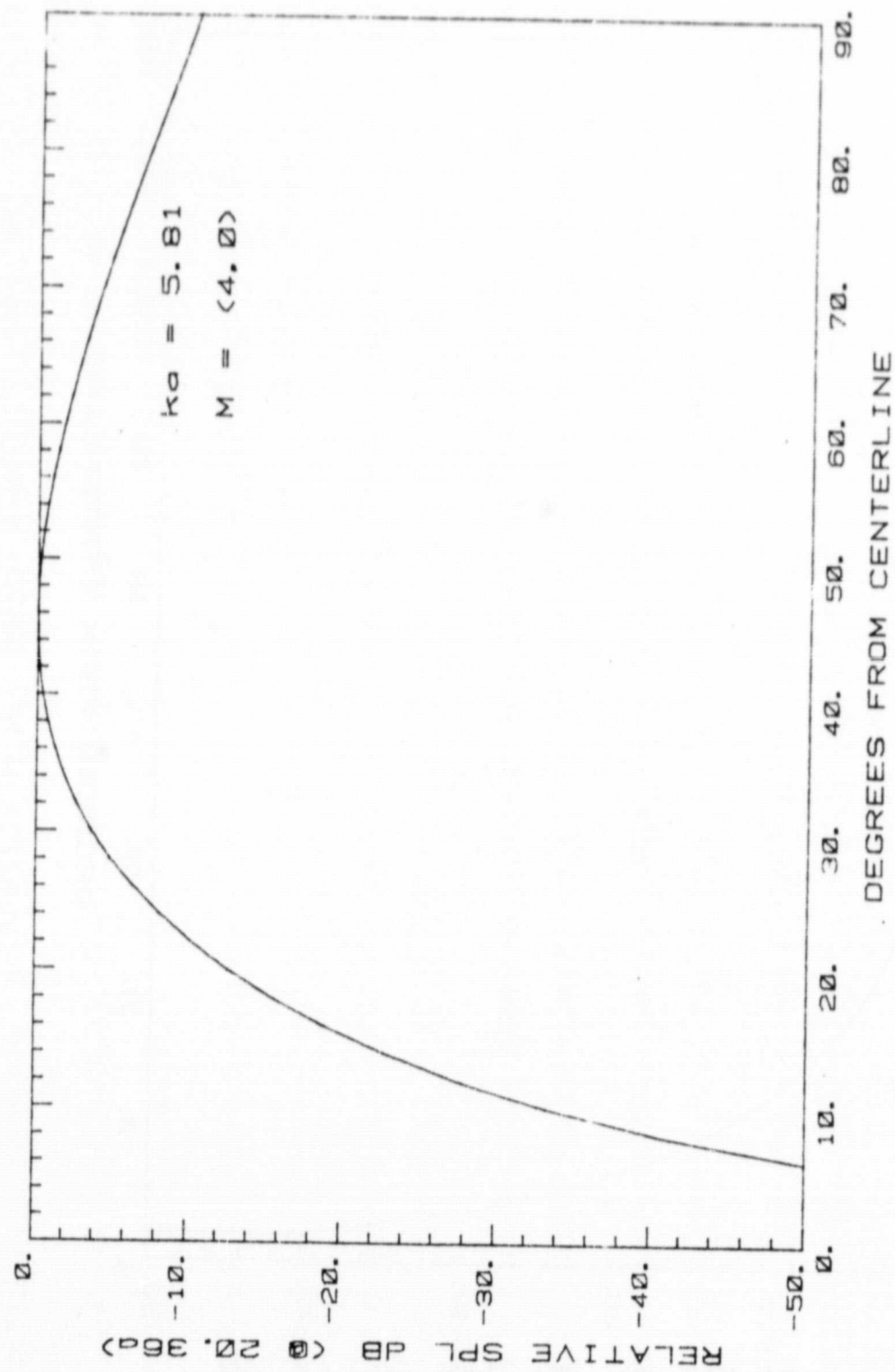
LANGLEY BELLMOUTH

Fig. 29



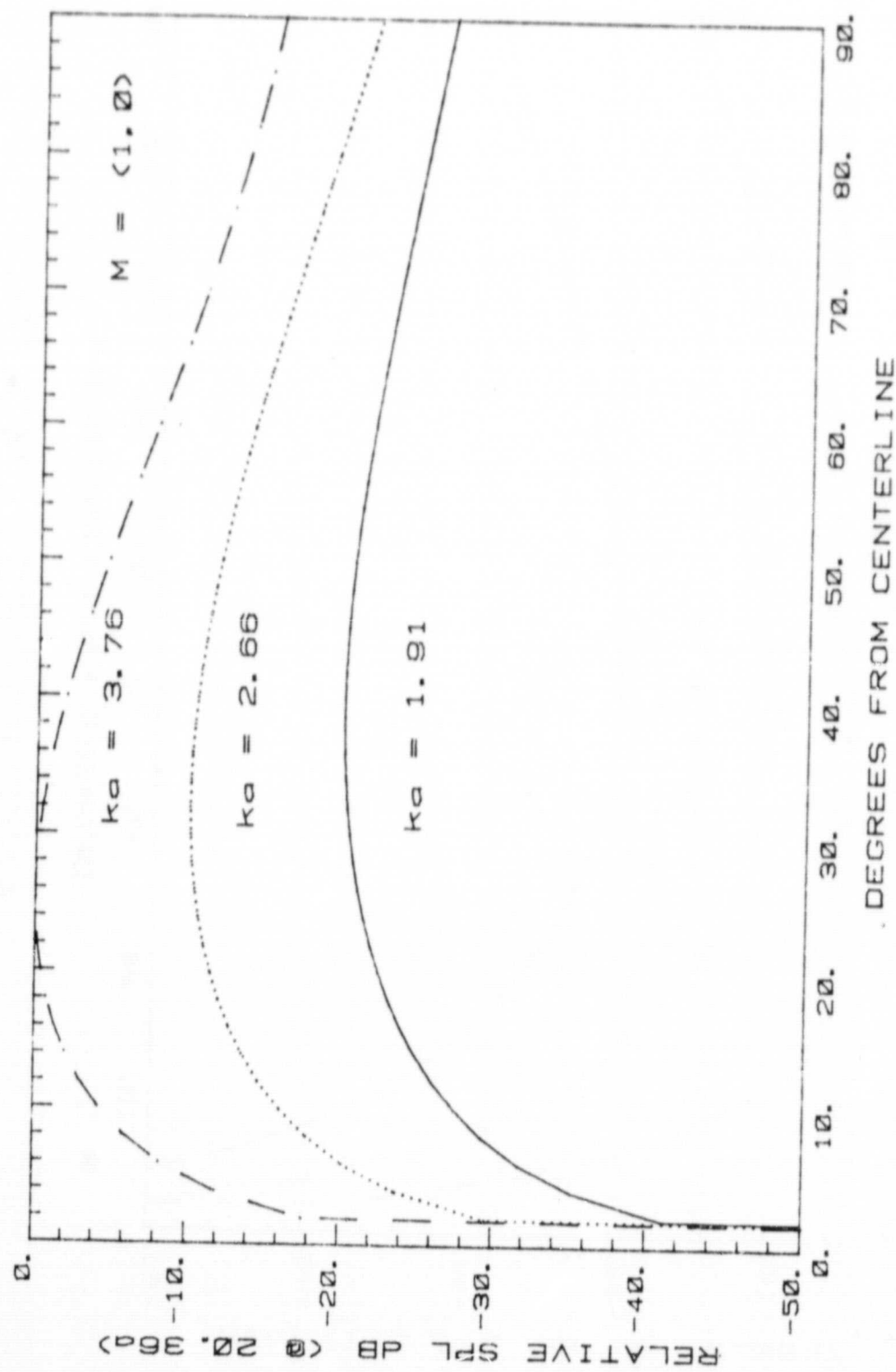
LANGLEY BELLMOUTH

Fig. 30



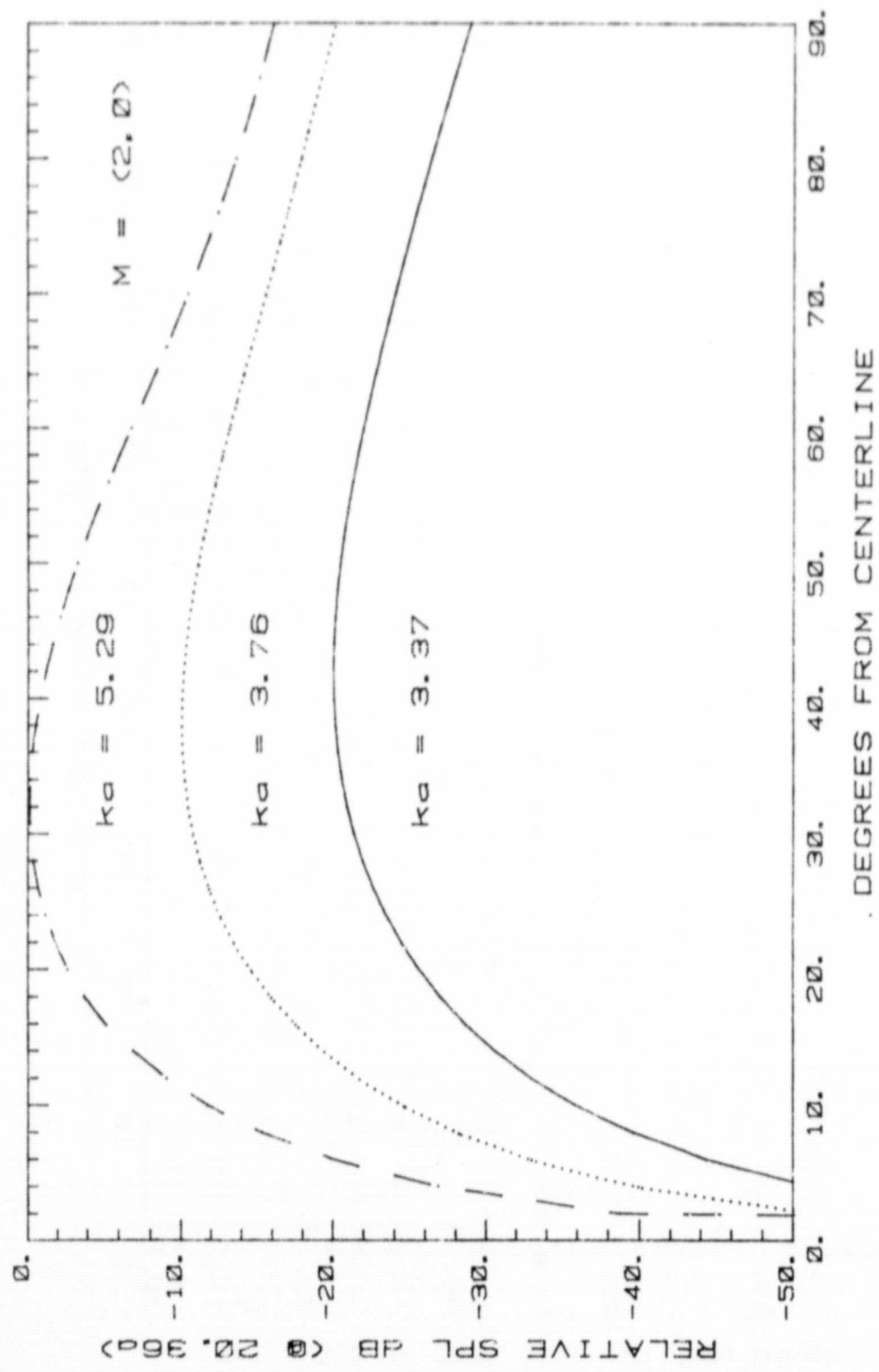
LANGLEY BELLMOUTH

Fig. 31



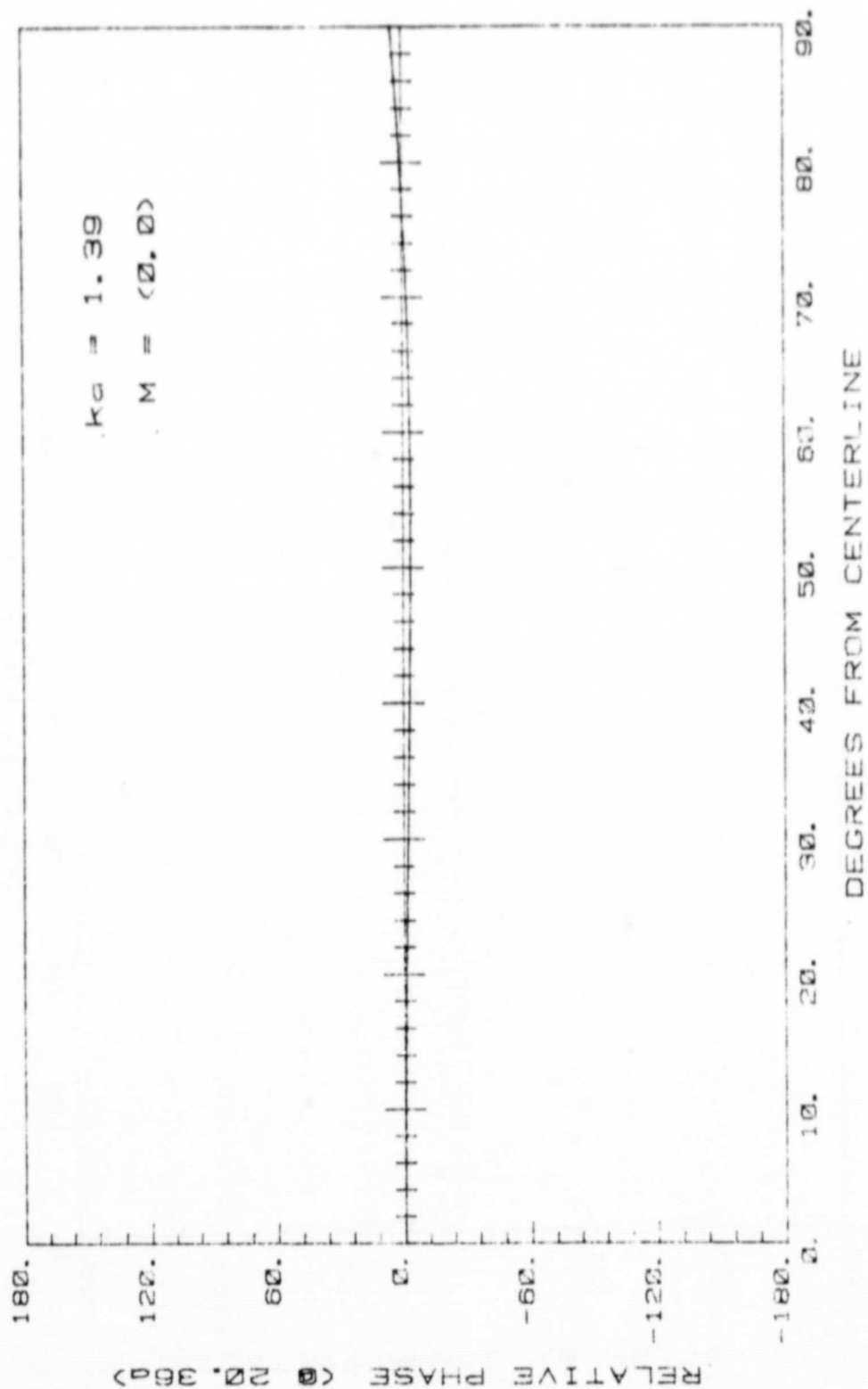
LANGLEY BELLMOUTH

Fig. 32



LANGLEY BELLMOUTH

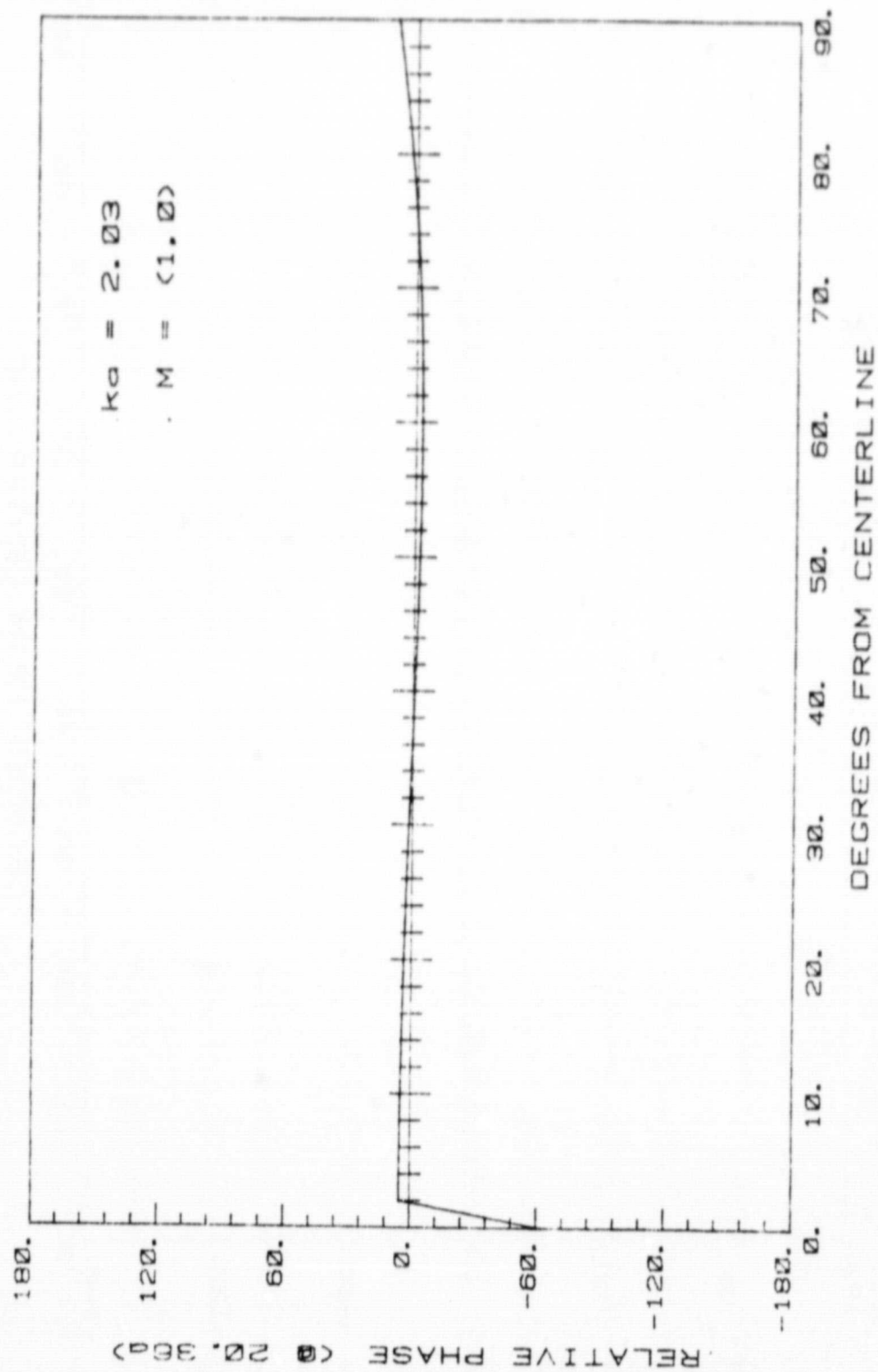
Fig. 33



LANGLEY BELLMOUTH

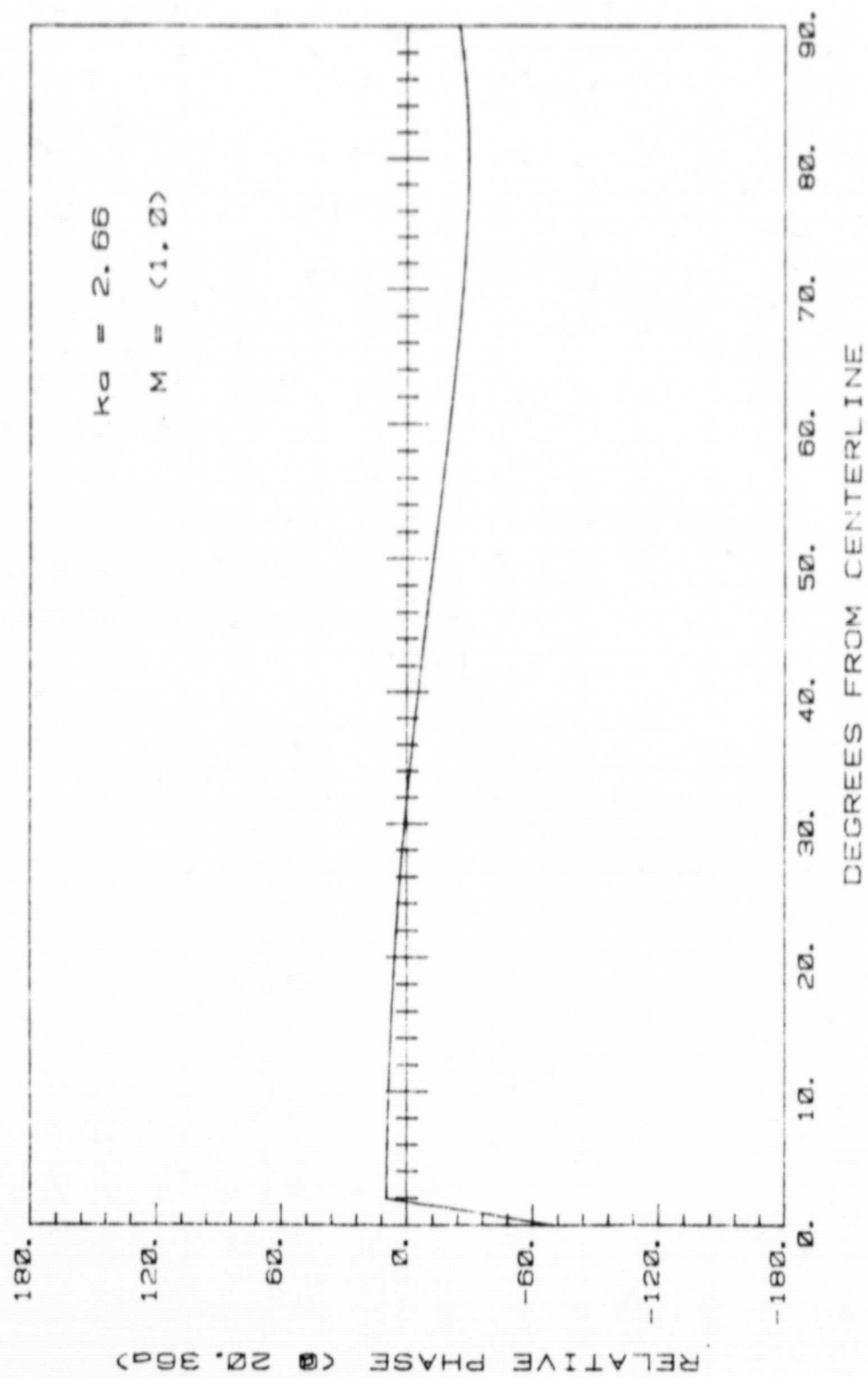
Fig. 34

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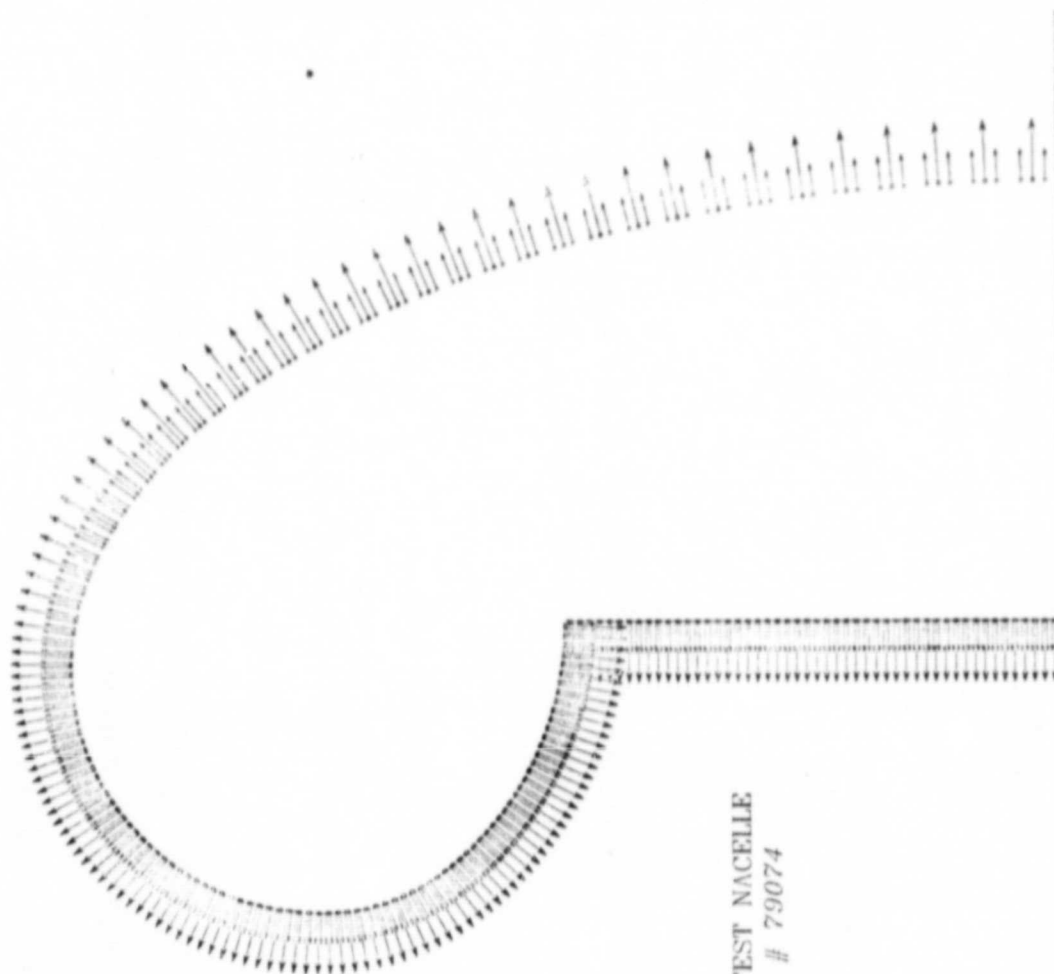
LANGLEY BELLMOUTH

Fig. 35



LANGLEY BELLMOUTH

Fig. 36



NASA LEWIS JT15D-1 GROUND TEST NACELLE
Geometry from: NASA TM # 79074
175 pts

Fig. 37 Lewis JT15D-1 Geometry used for Computer Calculations.

LEWIS JT15D-1

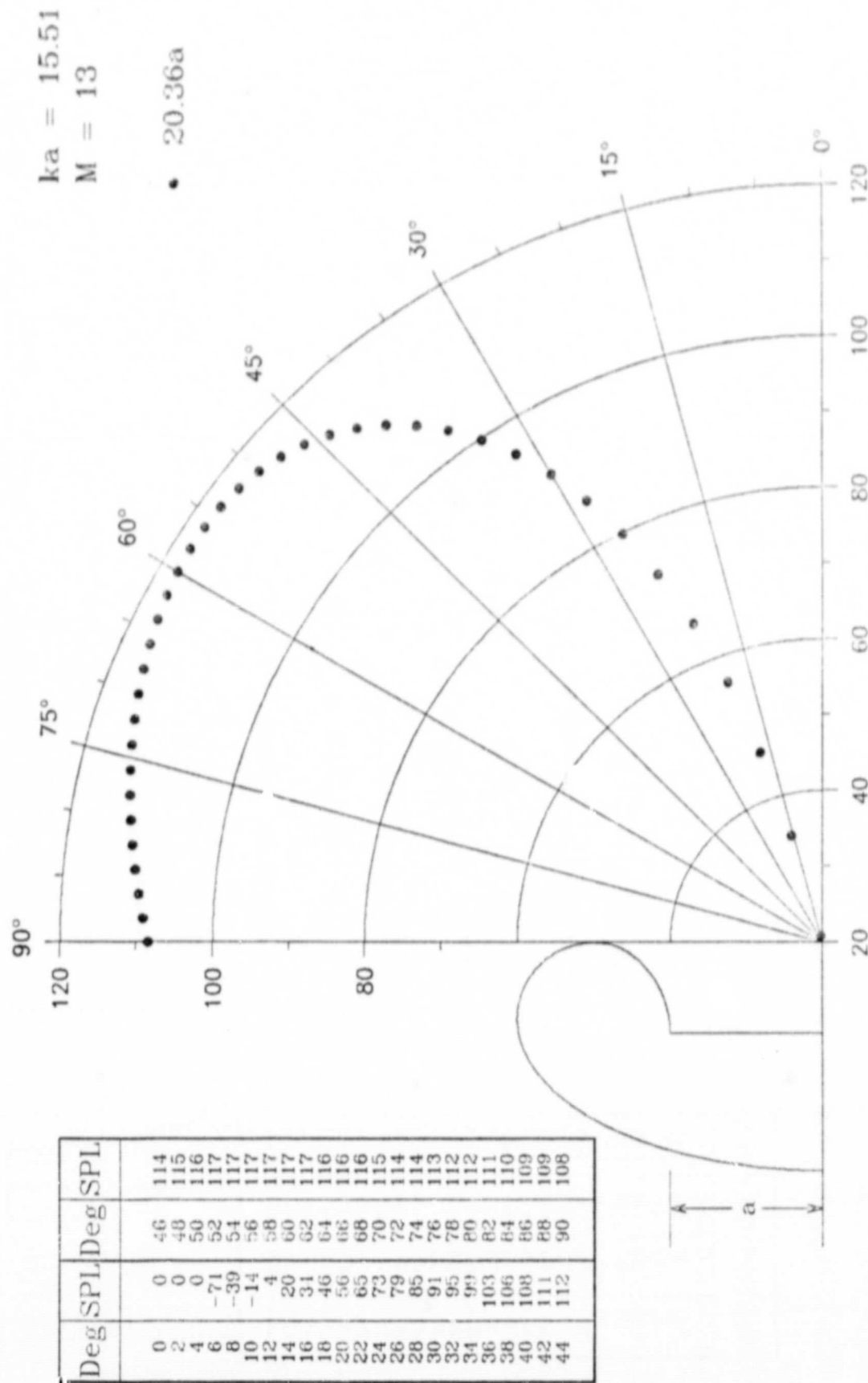


Fig. 38 SPL (dB)

LEWIS JT15D--1

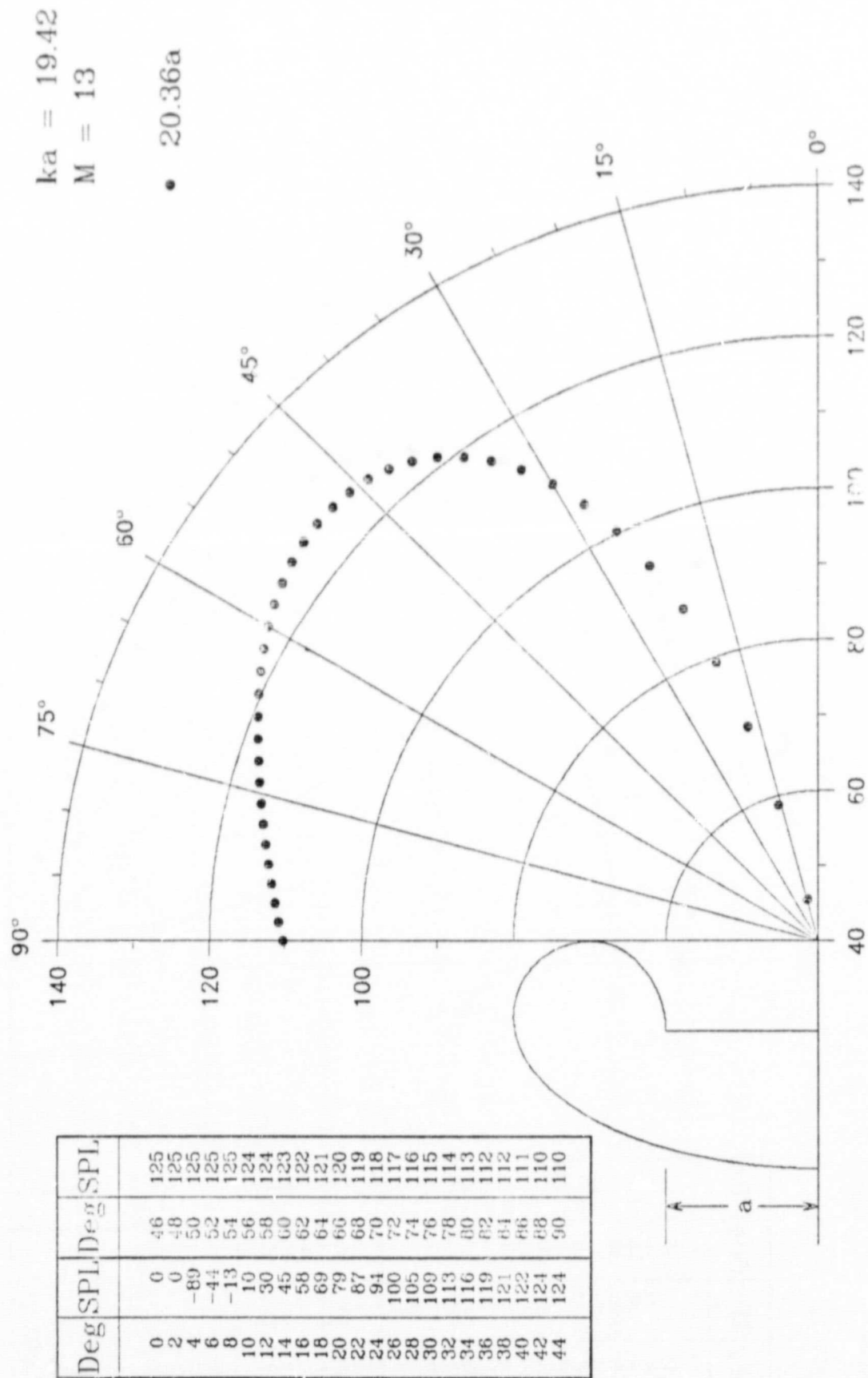
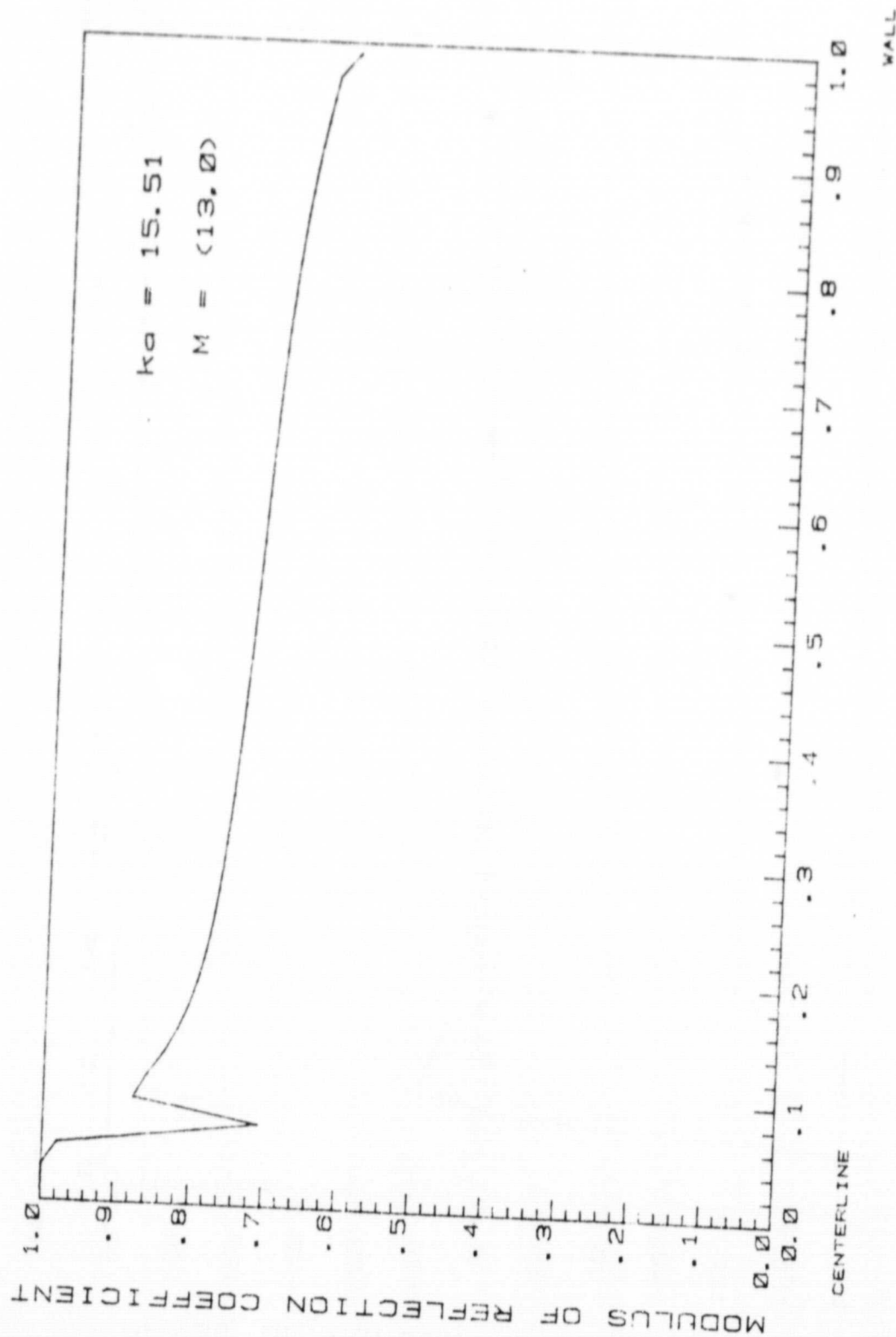
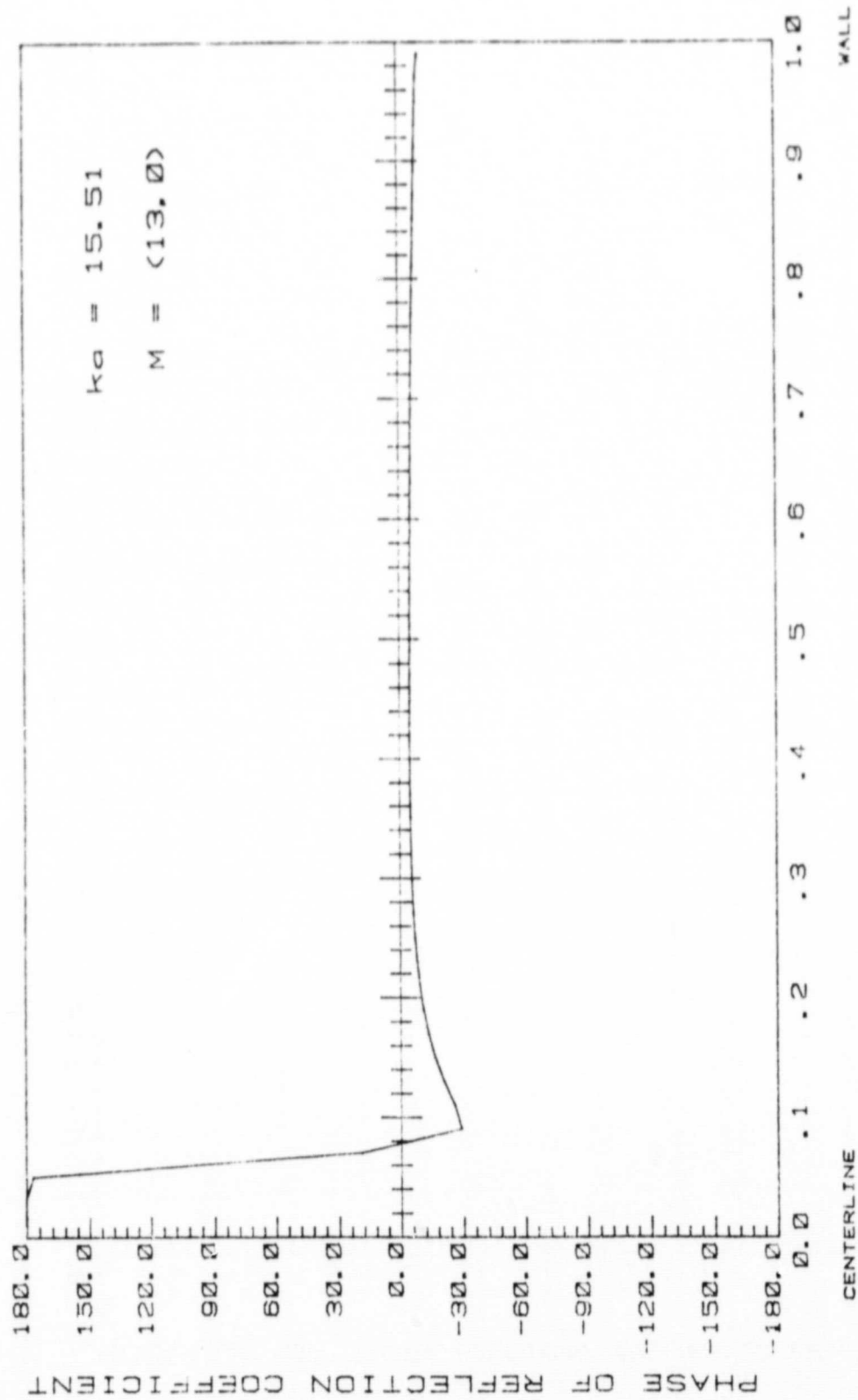


Fig. 39 SPL (dB)



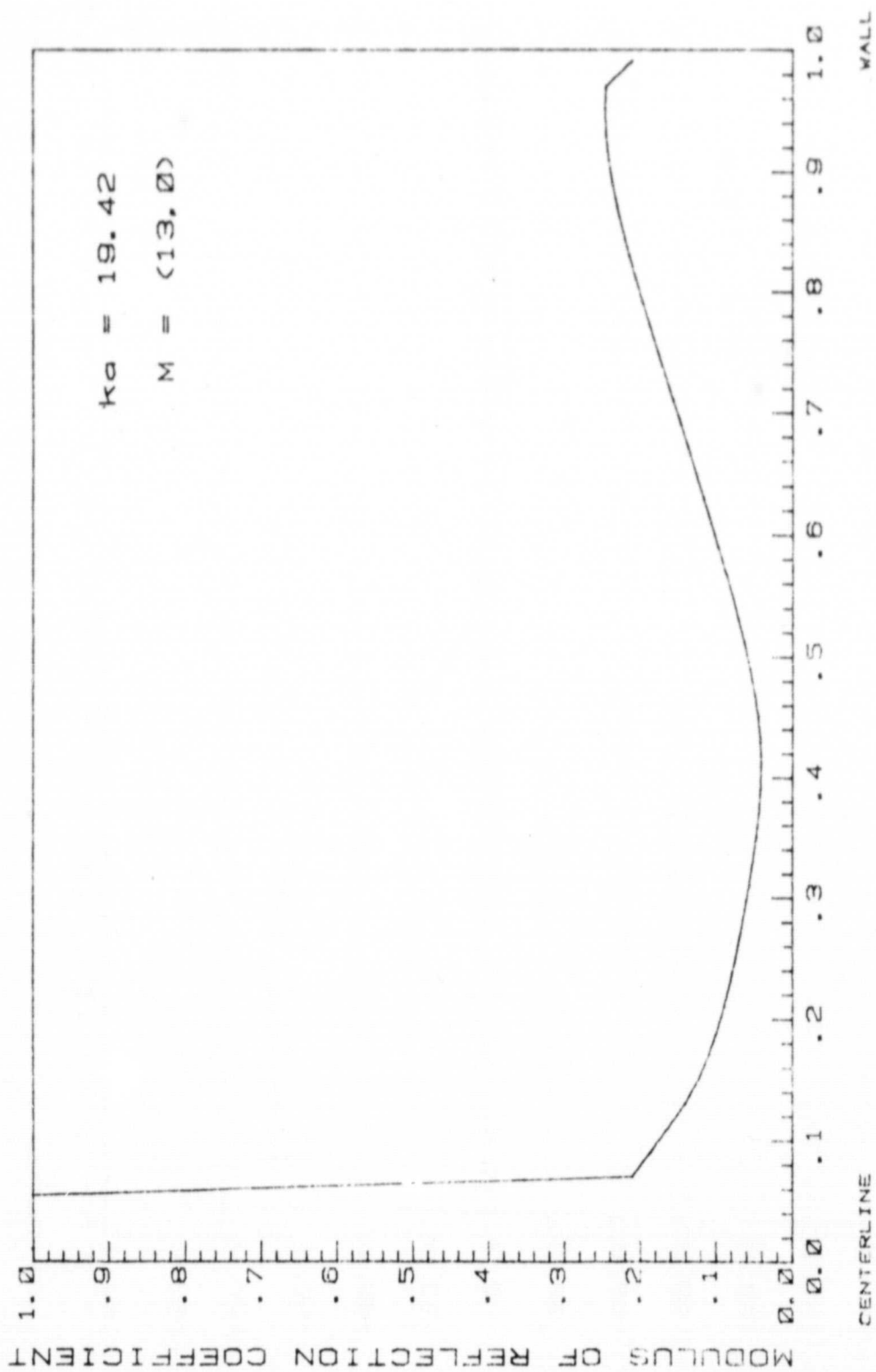
LEWIS JT15D-1 (Exit Plane)

Fig. 40



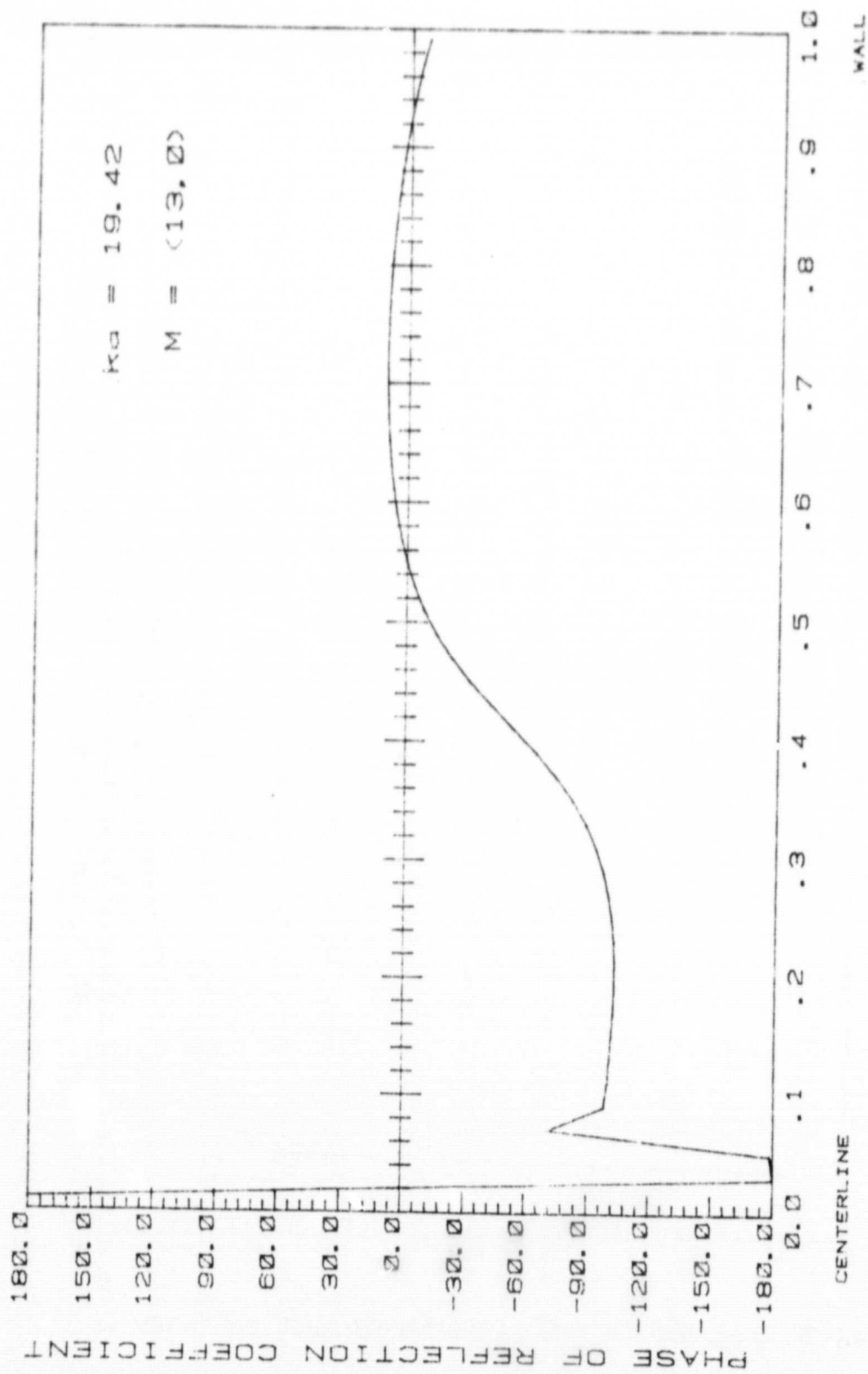
LEWIS JT150-1 (Exit Plane)

Fig. 41



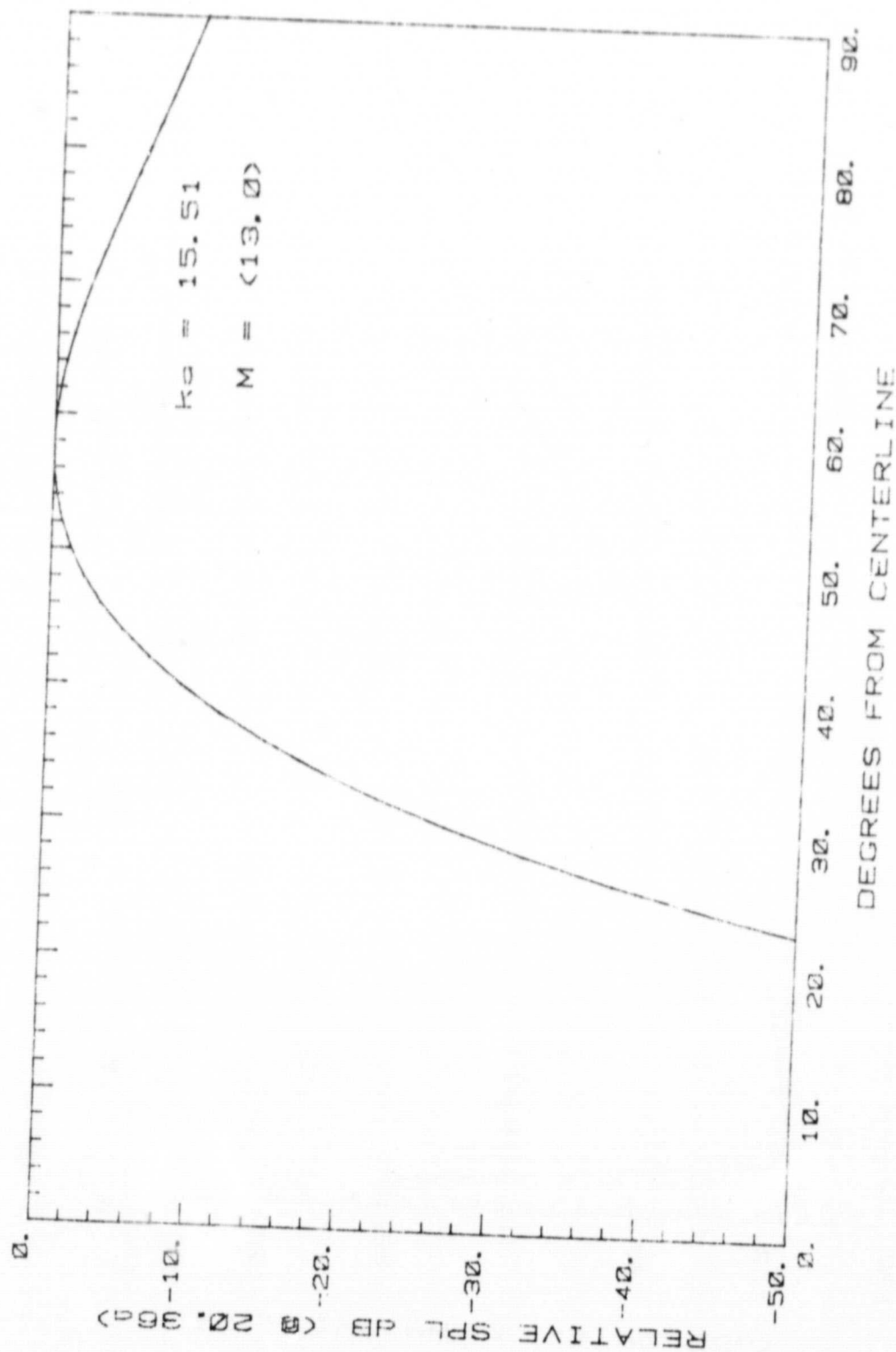
LEWIS JT15D-1 (Exit Plane)

Fig. 42



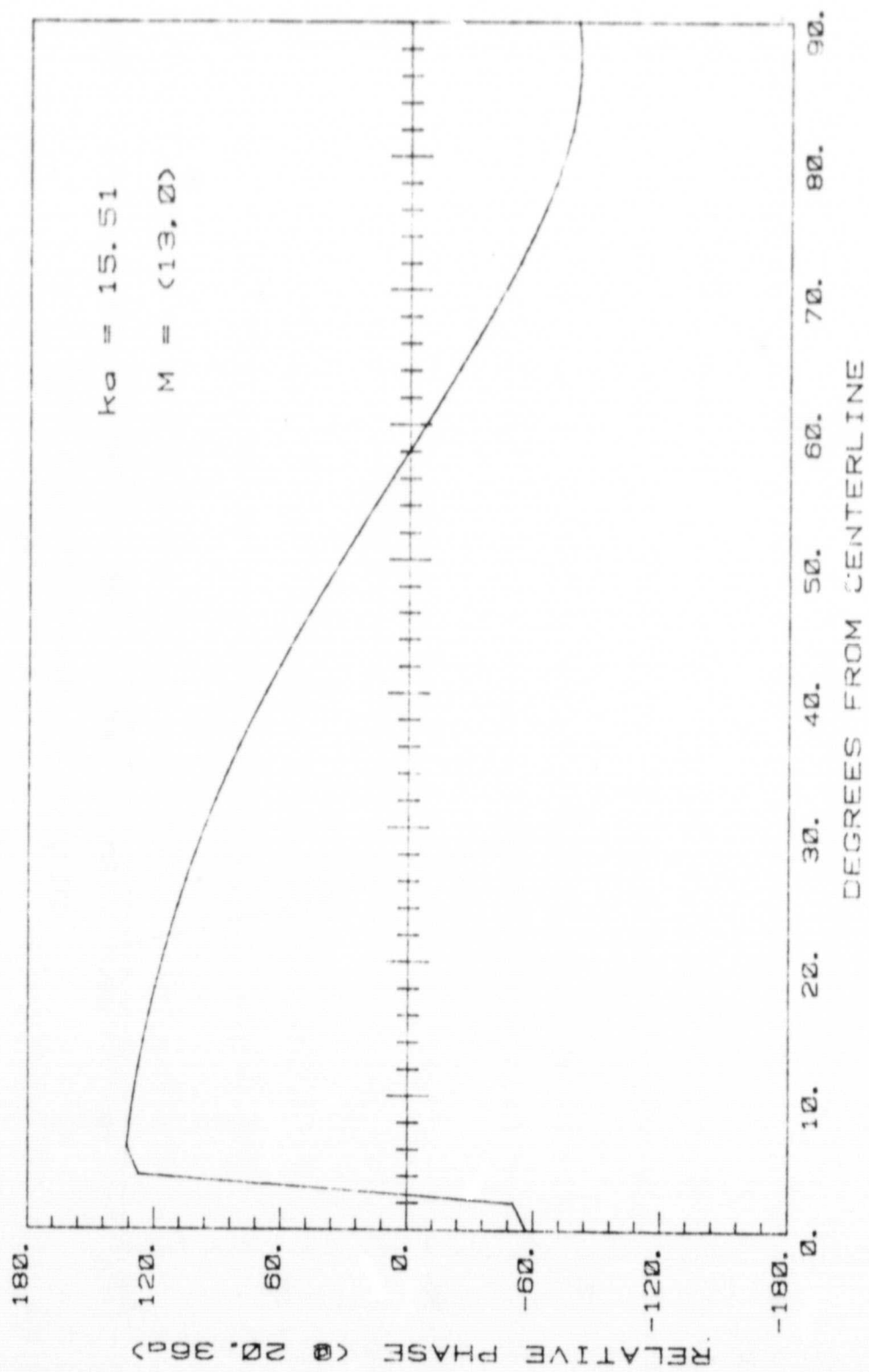
LEWIS JT15D-1 (Exit Plane)

Fig. 43



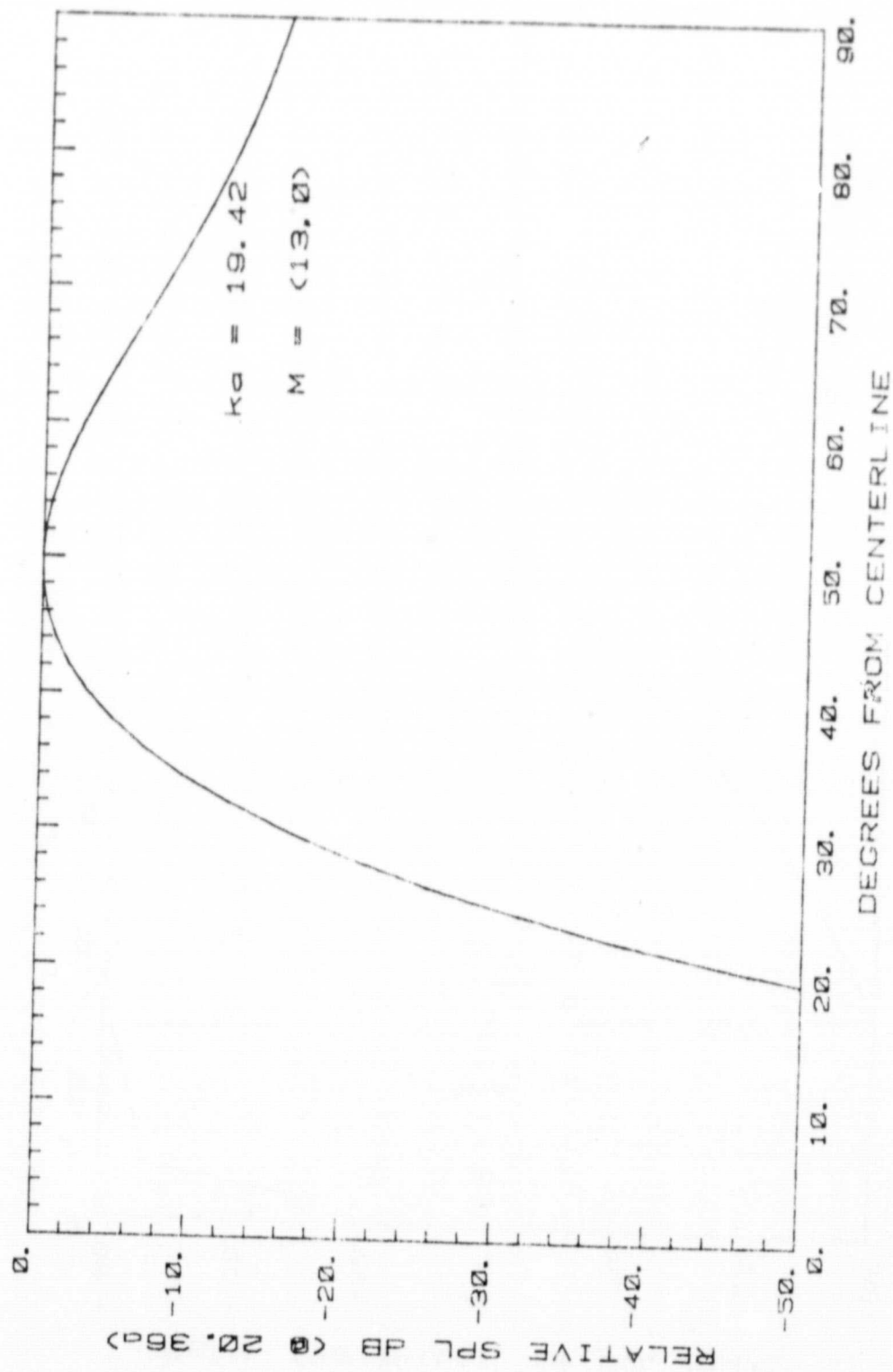
LEWIS JT15D-1

Fig. 44



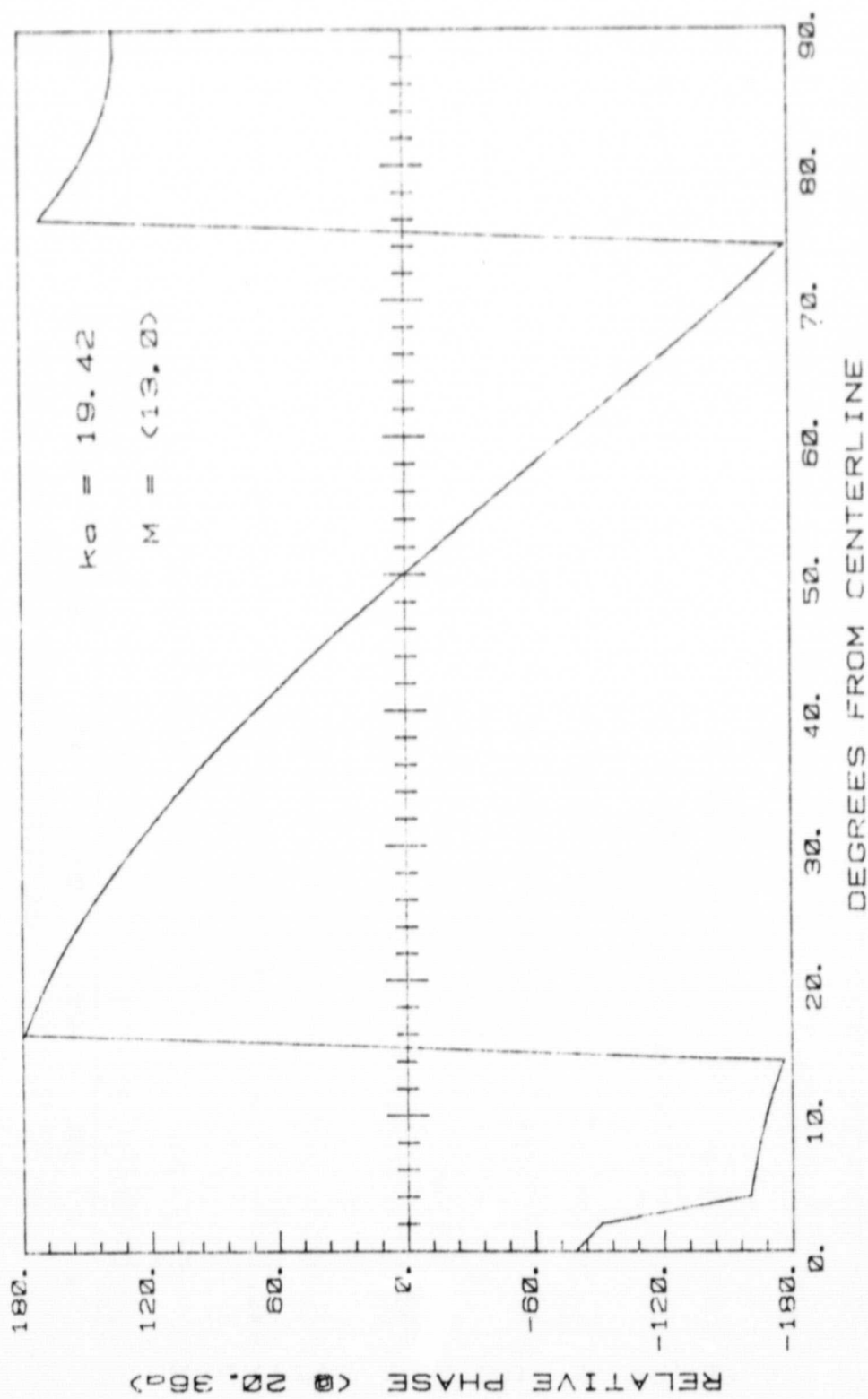
LEWIS JT15D-1

Fig. 45



LEWIS JT15D-1

Fig. 46



LEWIS JT15D-1

Fig. 47

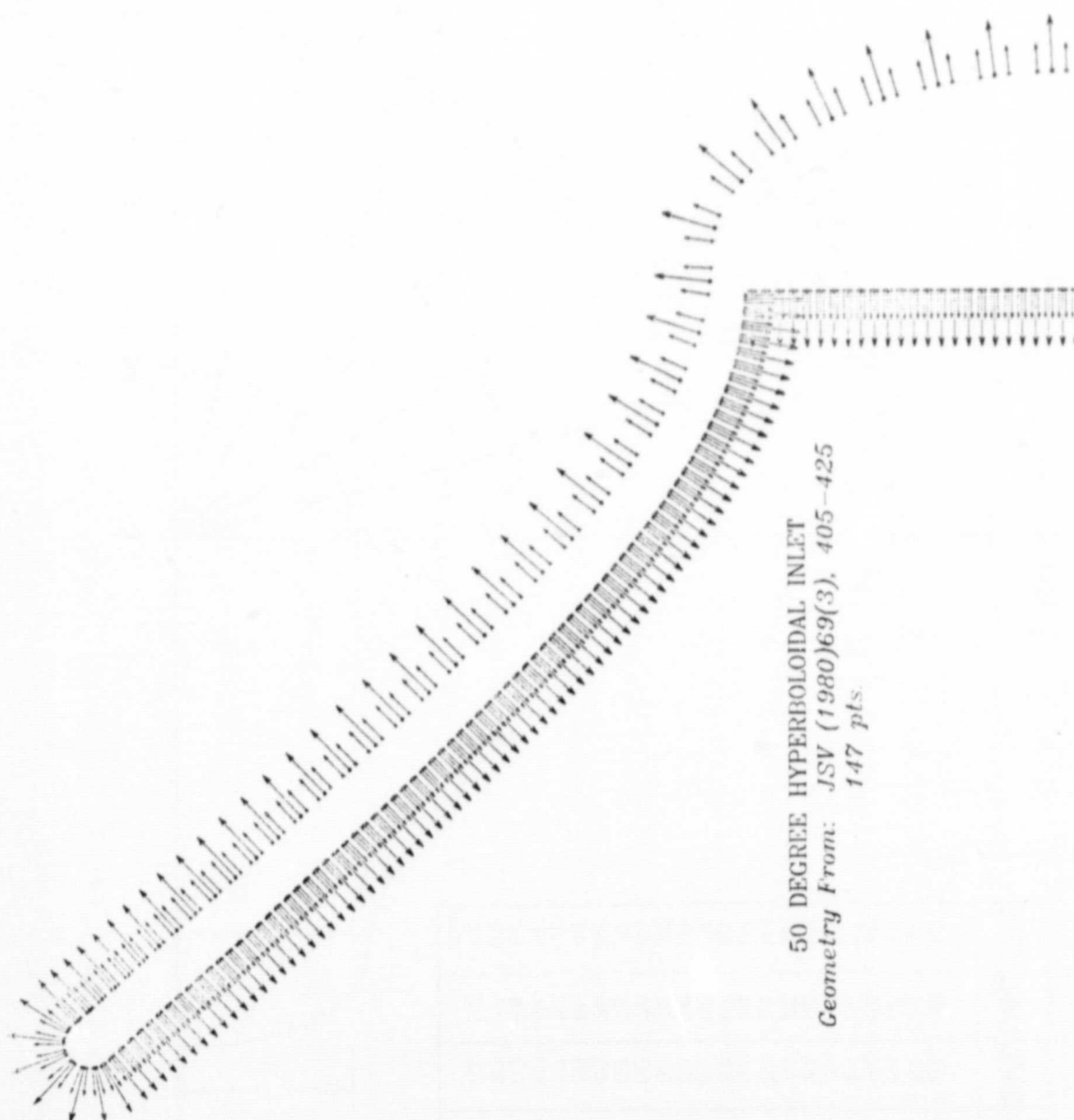


Fig. 48 50 Degree Hyperboloidal Inlet Geometry used
 for Computer Calculations.

50 DEGREE HYPERBOLOIDAL INLET

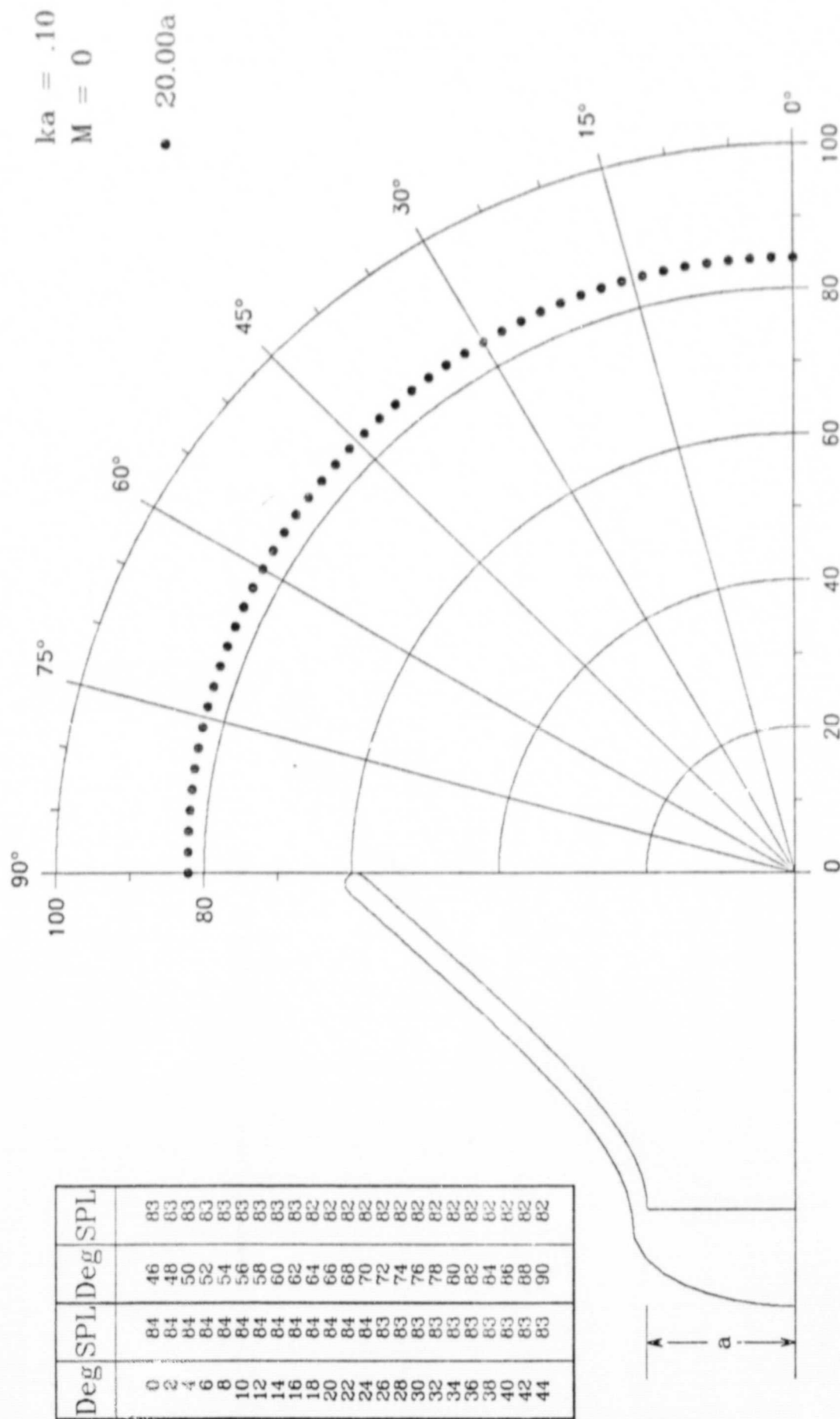


Fig. 49 SPL (dB)

50 DEGREE HYPERBOLOIDAL INLET

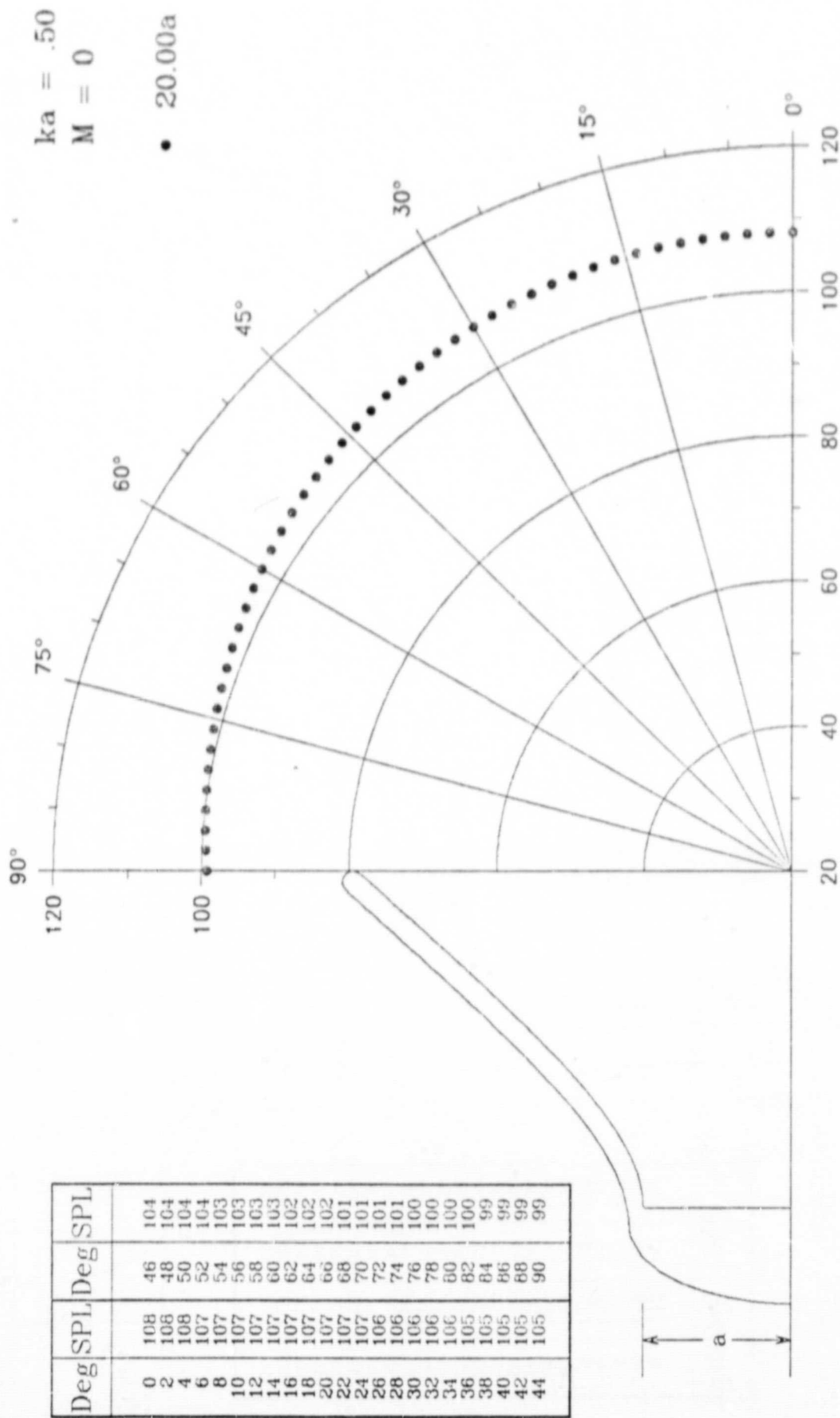


Fig. 50 SPL (dB)

50 DEGREE HYPERBOLOIDAL INLET

Deg SPL	Deg SPL	Deg SPL
0	119	112
2	119	111
4	119	111
6	119	111
8	119	110
10	119	110
12	119	109
14	118	109
16	118	108
18	118	108
20	118	107
22	117	107
24	117	106
26	117	106
28	116	105
30	116	105
32	115	104
34	115	104
36	114	103
38	114	103
40	113	102
42	113	102
44	112	102

$ka = 1.00$
 $M = 0$

• 20.00a

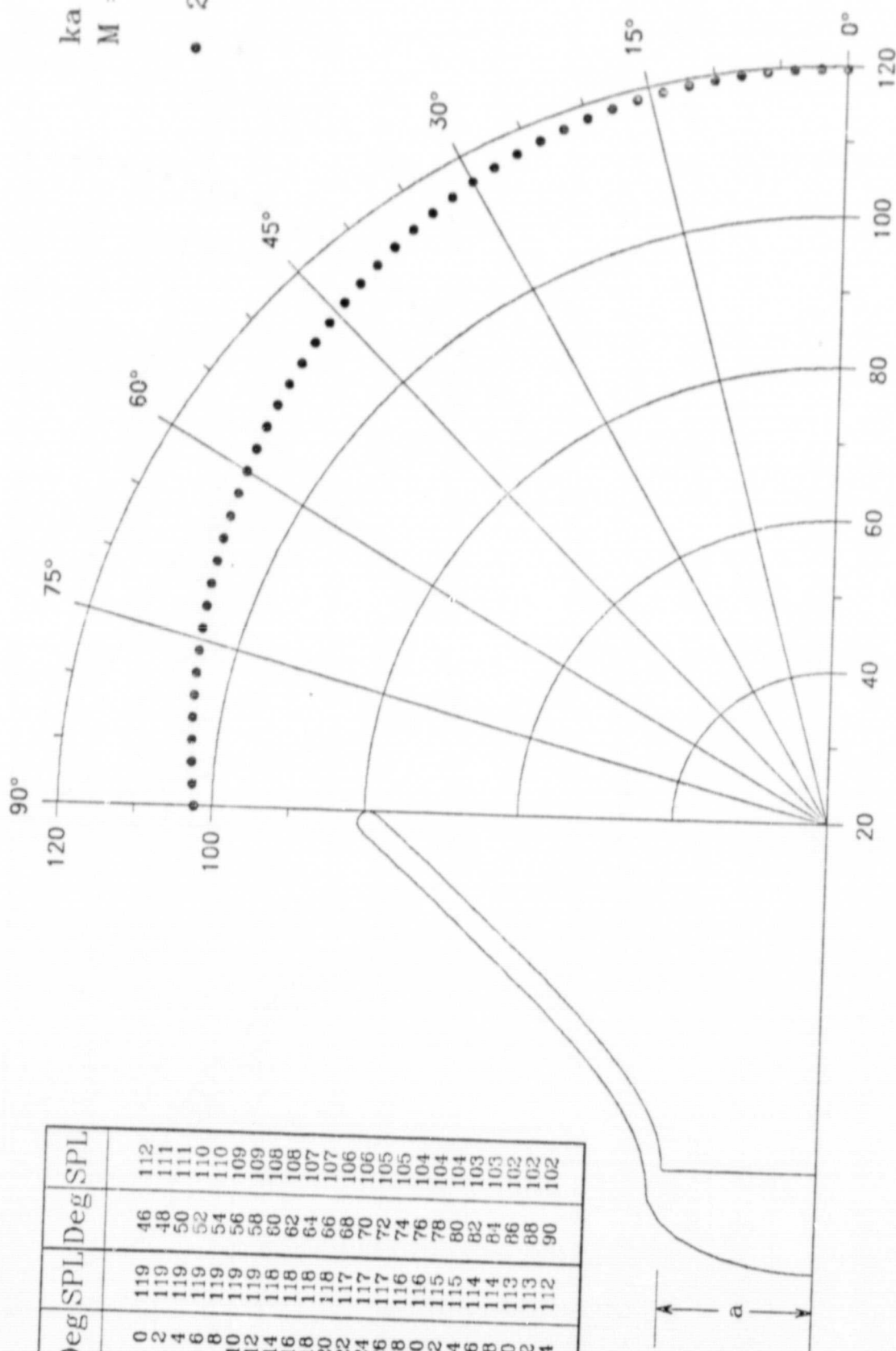
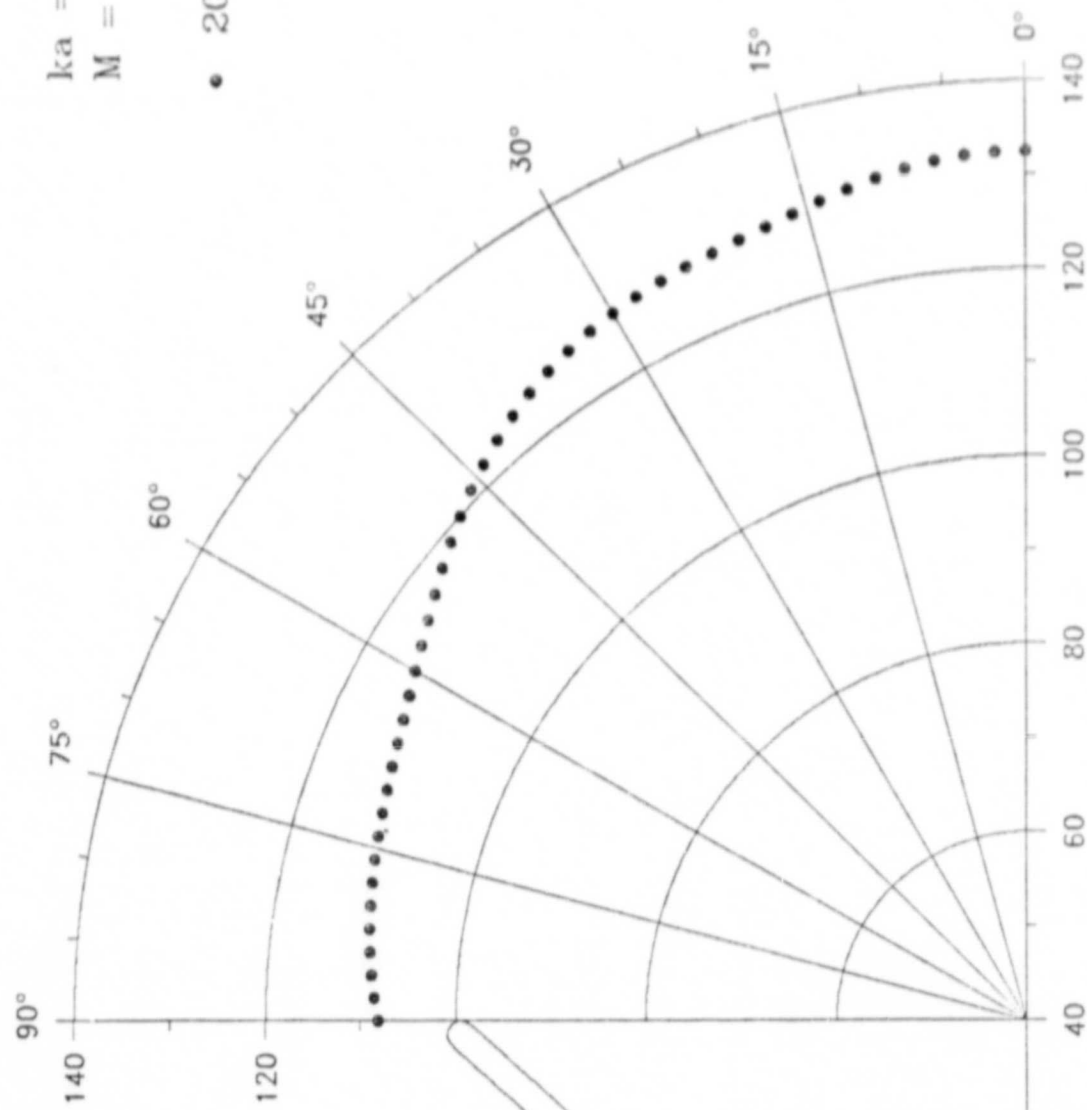


Fig. 51 SPL (dB)

50 DEGREE HYPERBOLOIDAL INLET

$ka = 2.50$
 $M = 0$

• 20.00a



Deg	SPL	Deg	SPL
0	132	46	121
2	132	48	119
4	132	50	118
6	131	52	117
8	131	54	116
10	130	56	115
12	130	58	114
14	129	60	114
16	128	62	113
18	128	64	112
20	128	66	112
22	127	68	111
24	127	70	111
26	127	72	111
28	127	74	110
30	126	76	110
32	126	78	110
34	125	80	109
36	125	82	109
38	124	84	109
40	123	86	108
42	122	88	108
44	122	90	108

Fig. 52 SPL (dB)

50 DEGREE HYPERBOLOIDAL INLET

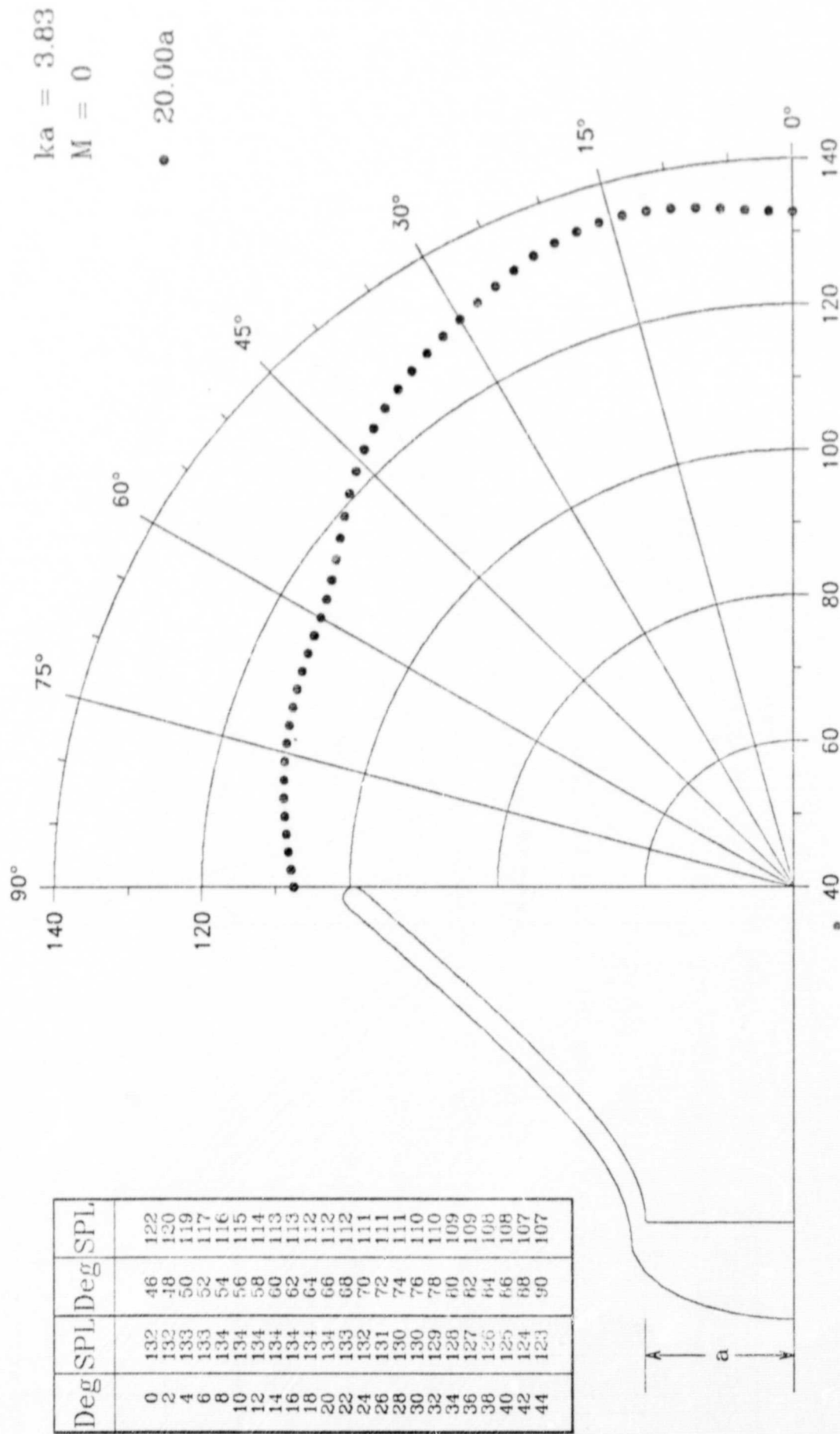


Fig. 53 SPL (dB)

50 DEGREE HYPERBOLOIDAL INLET

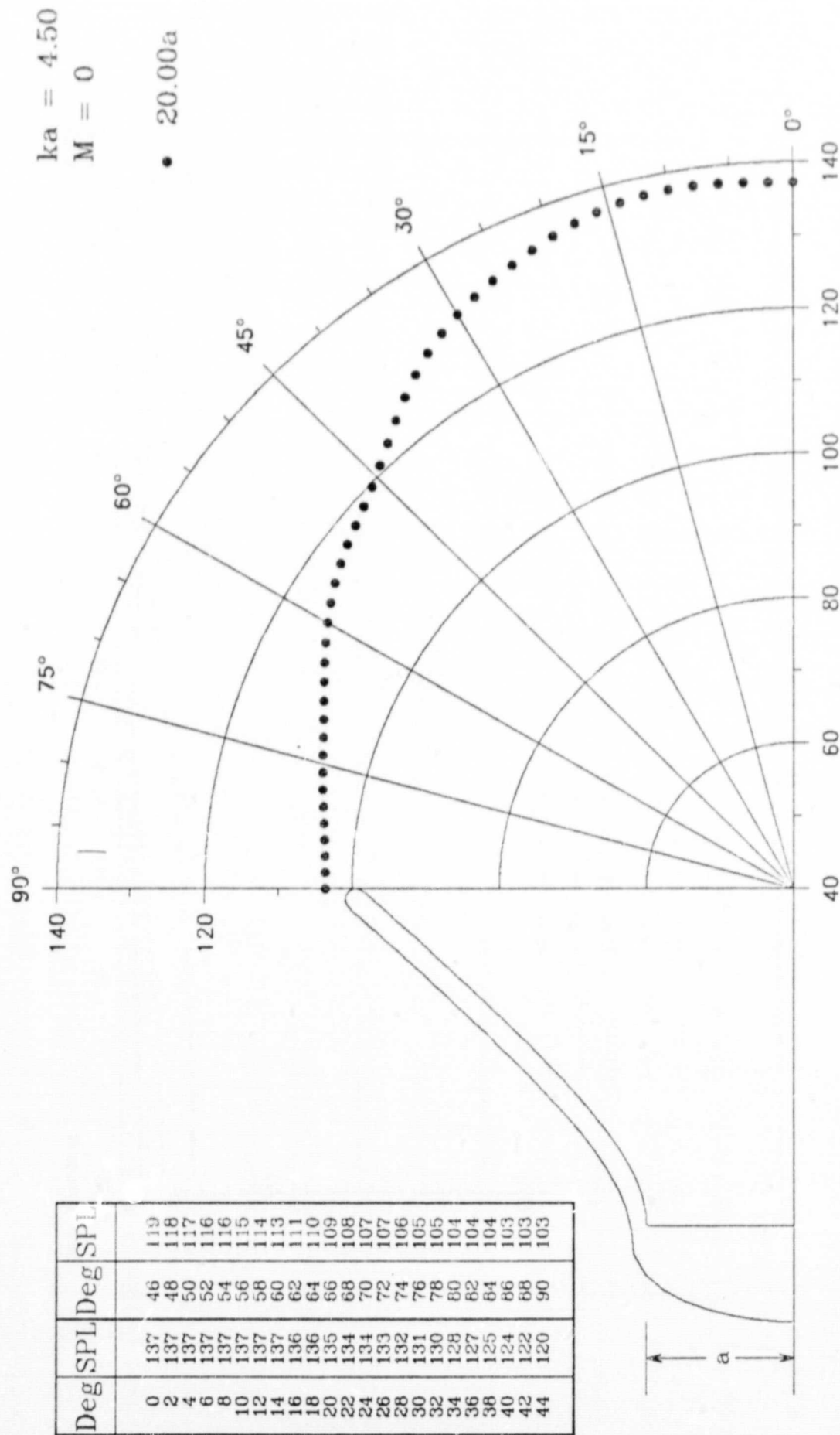
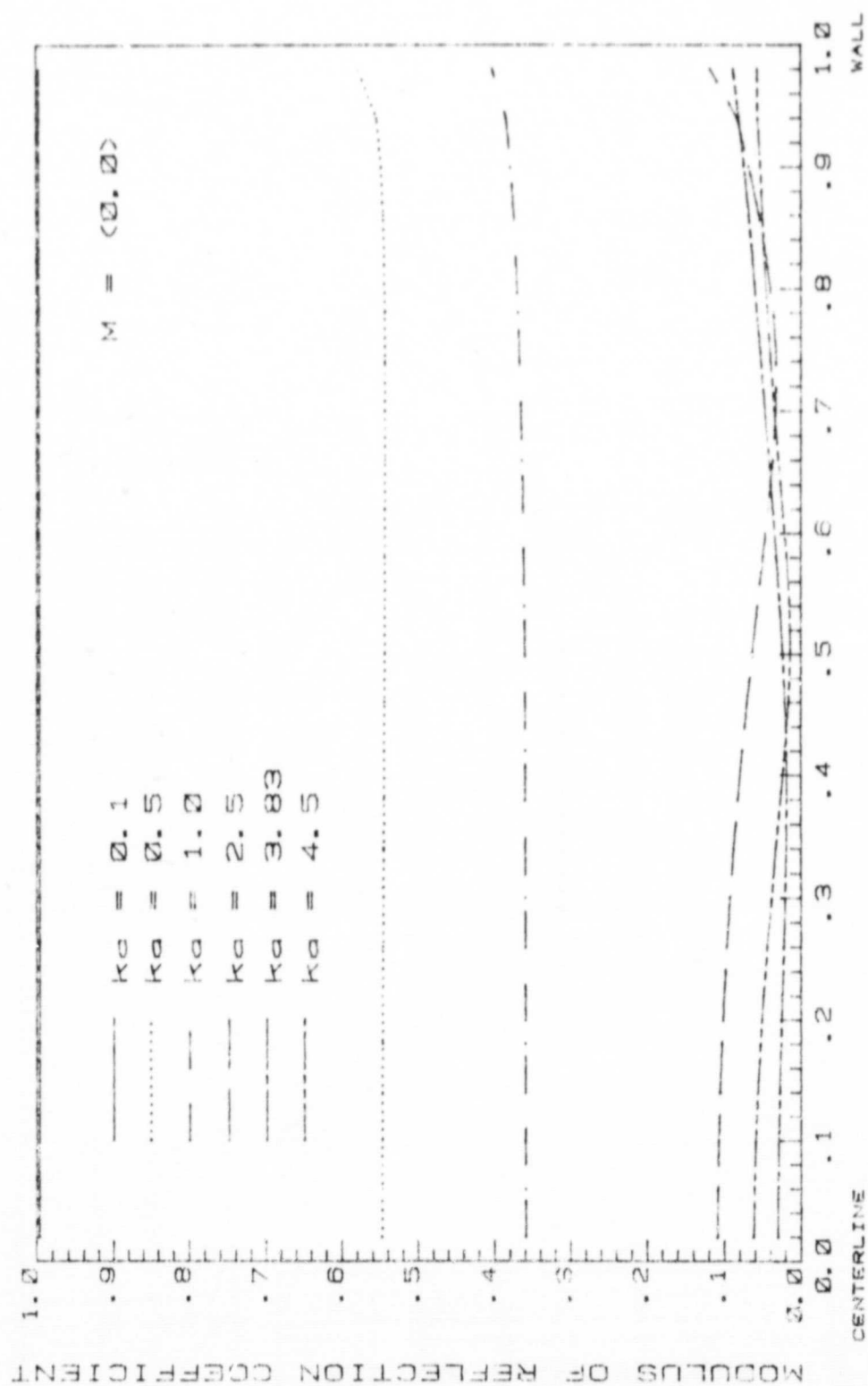
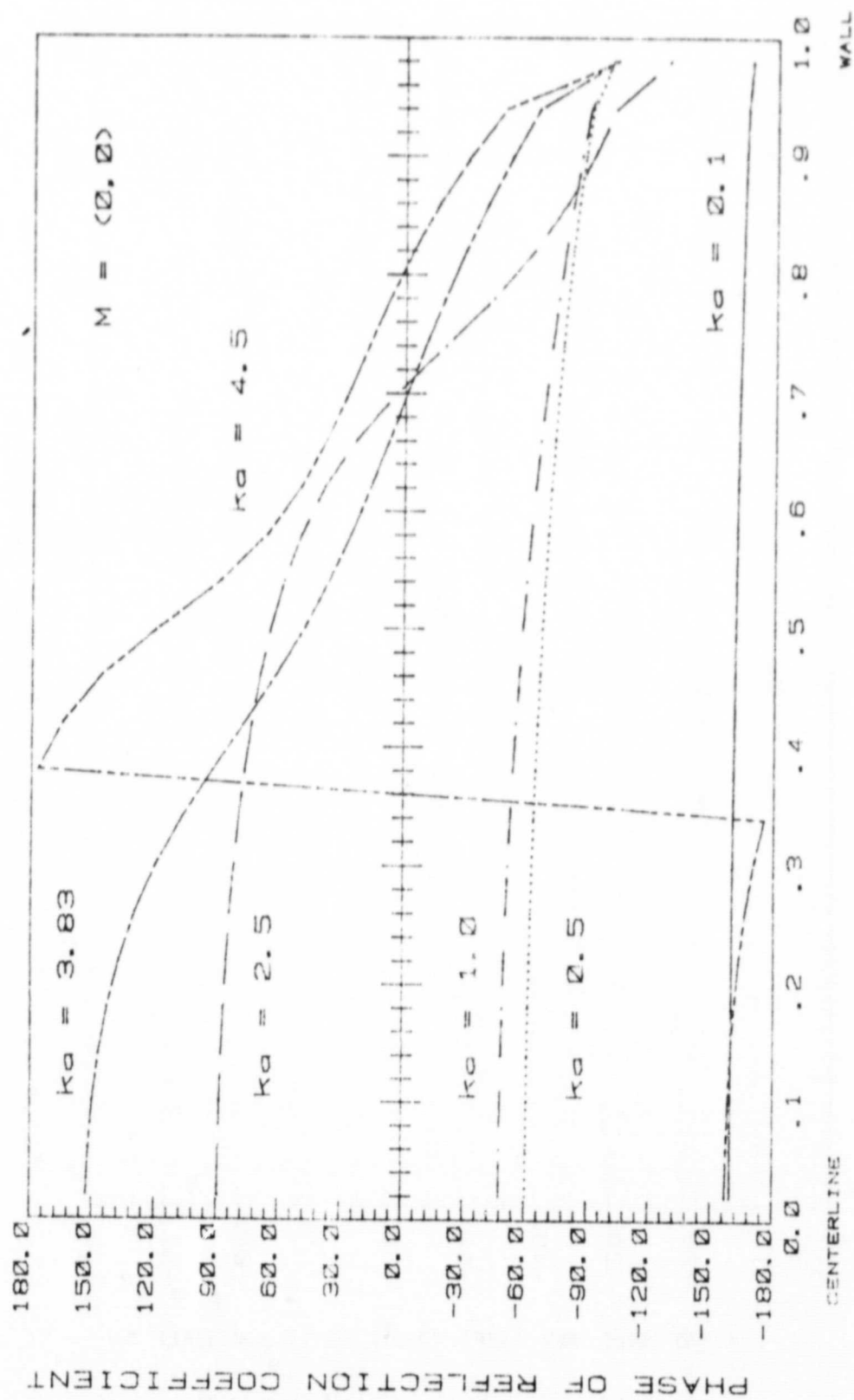


Fig. 54 SPL (dB)



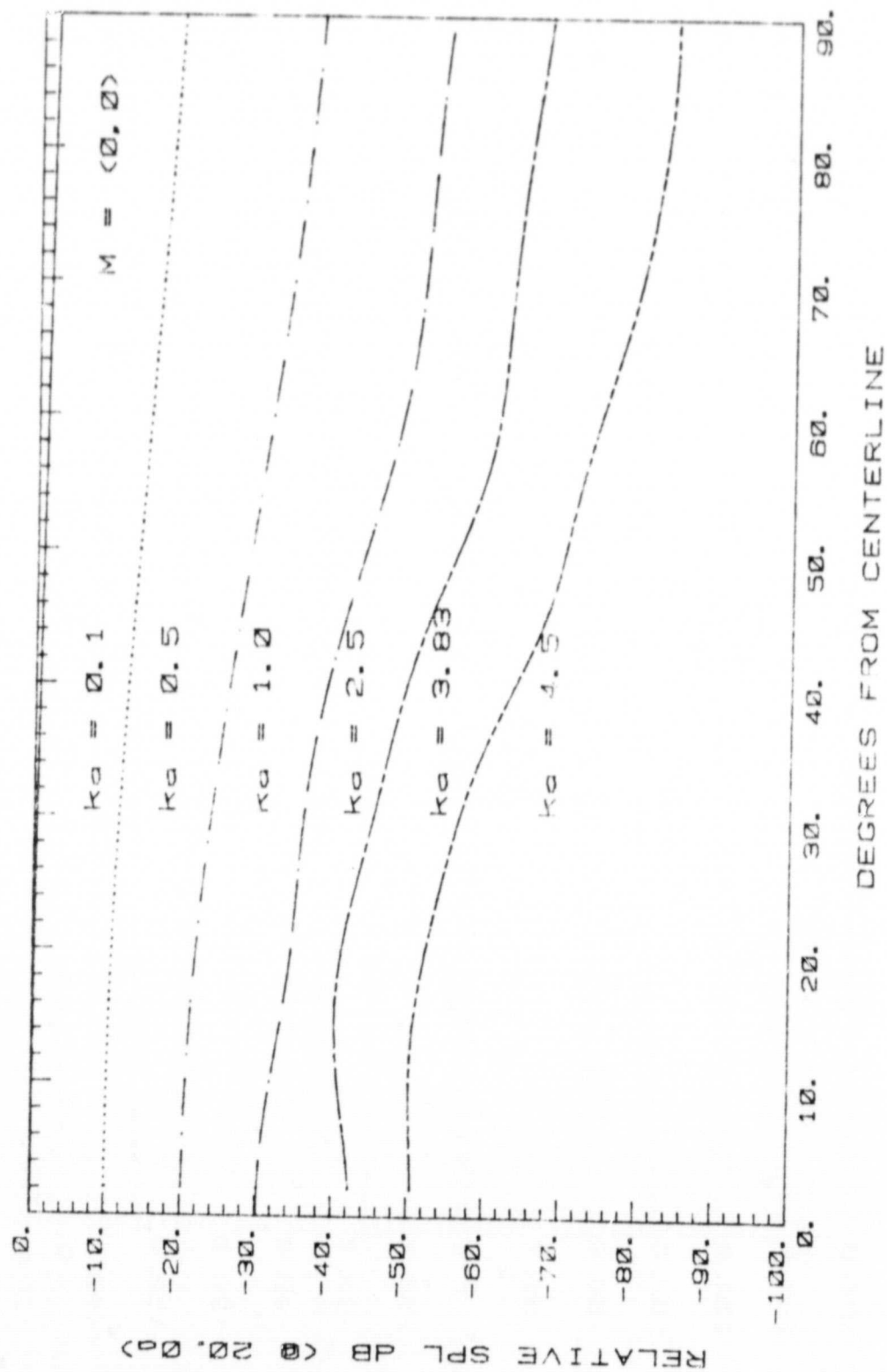
50° HYPERBOLOIDAL INLET (Exit Plane)

Fig. 55



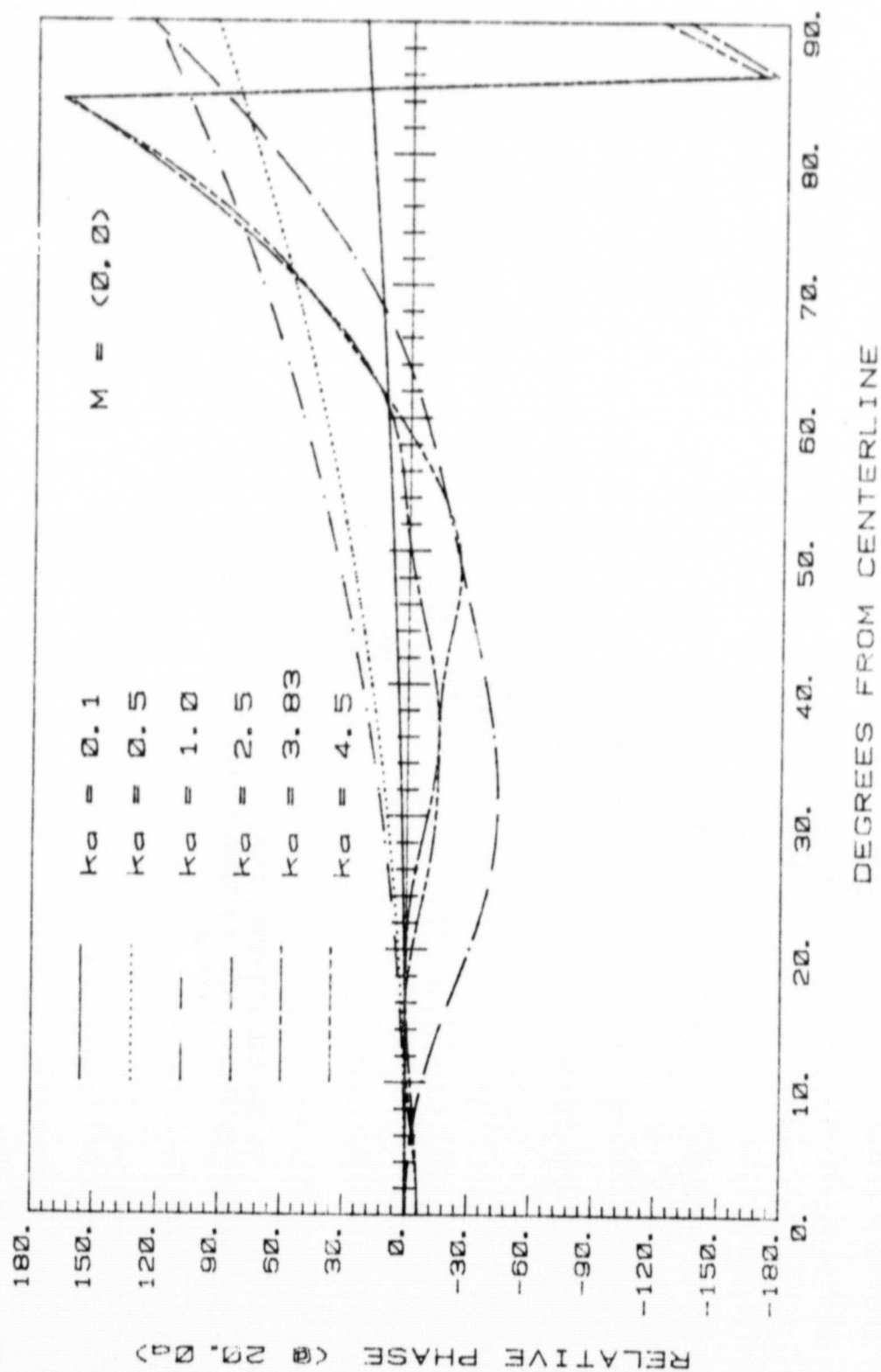
50° HYPERBOLOIDAL INLET (Exit Plane)

Fig. 56



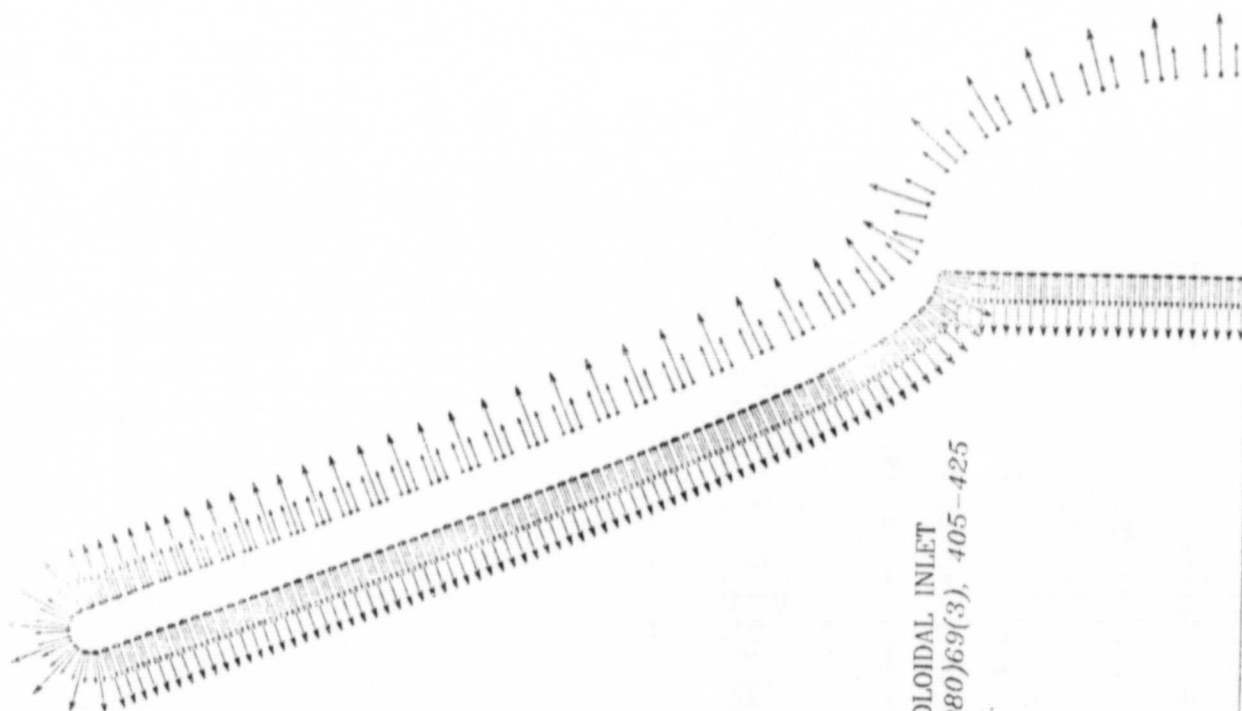
50° HYPERBOLOIDAL INLET

Fig. 57



50° HYPERBOLOIDAL INLET

Fig. 58



70 DEGREE HYPERBOLOIDAL INLET
Geometry From: JSV (1980)69(3), 405-425
146 pts.

Fig. 59 70 Degree Hyperboloidal Inlet Geometry used
for Computer Calculations.

70 DEGREE HYPERBOLOIDAL INLET

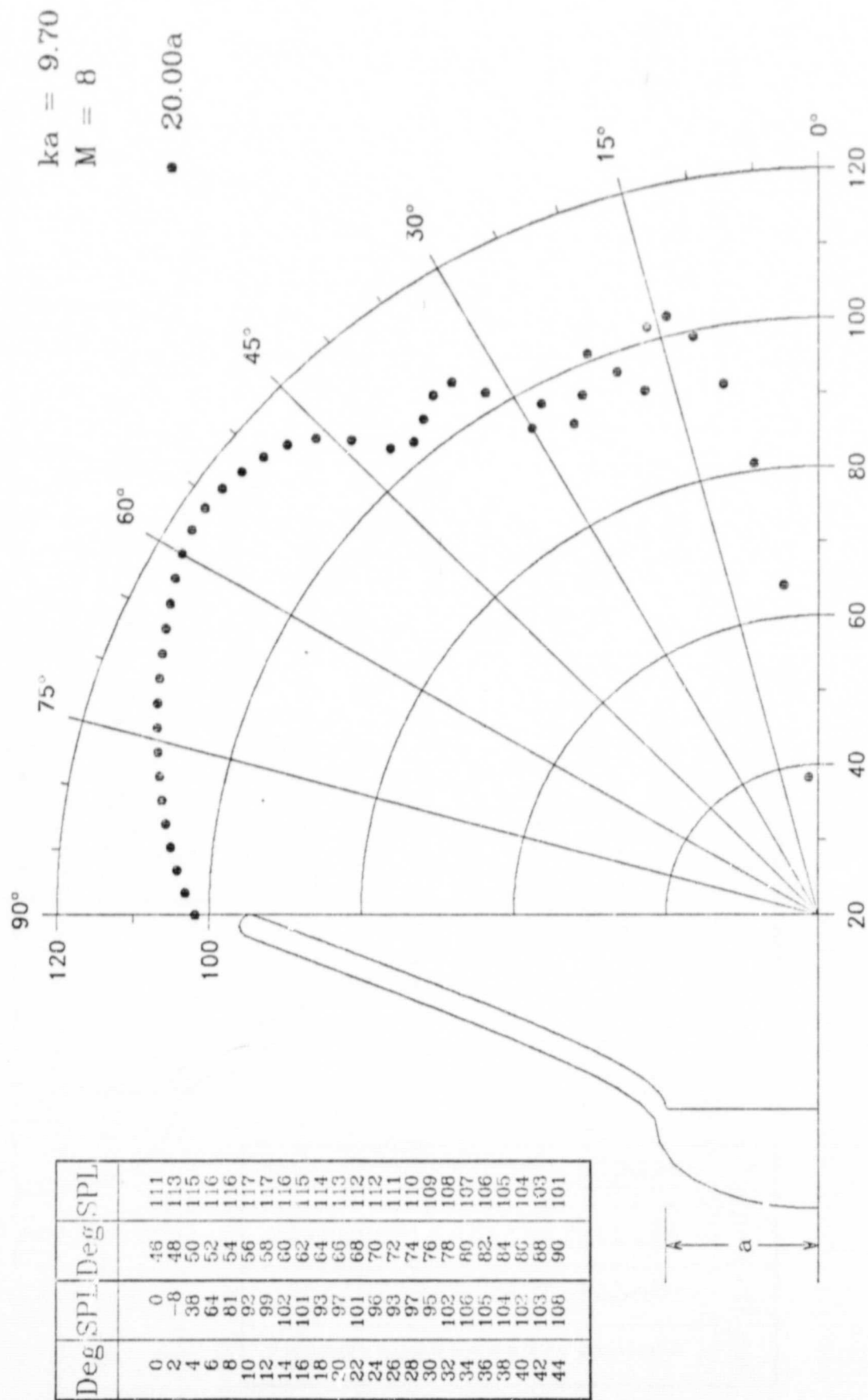


Fig. 60 SPL (dB)

70 DEGREE HYPERBOLOIDAL INLET

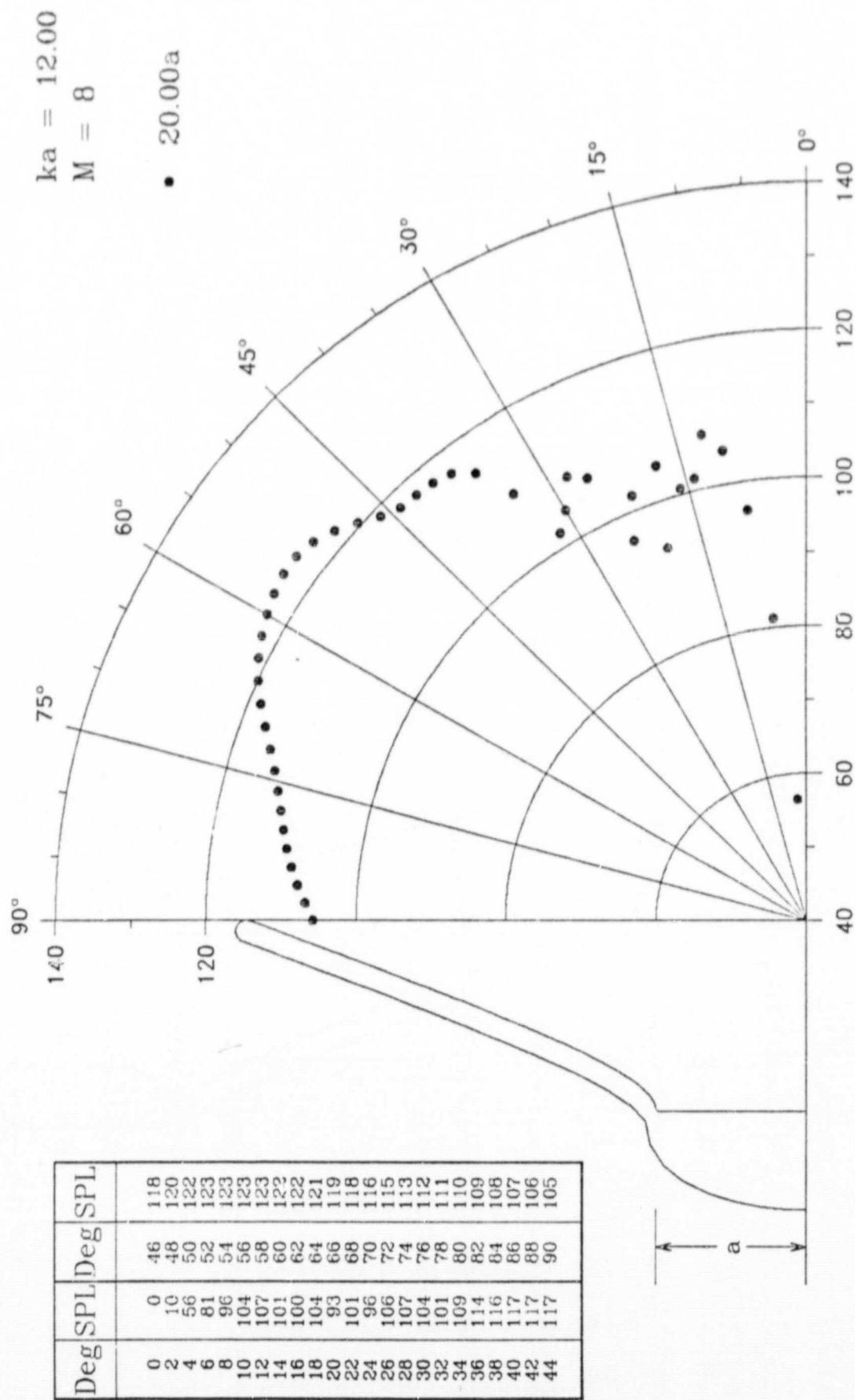


Fig. 61 SPL (dB)

70 DEGREE HYPERBOLOIDAL INLET

$ka = 16.00$

$M = 8$

• 20.00a

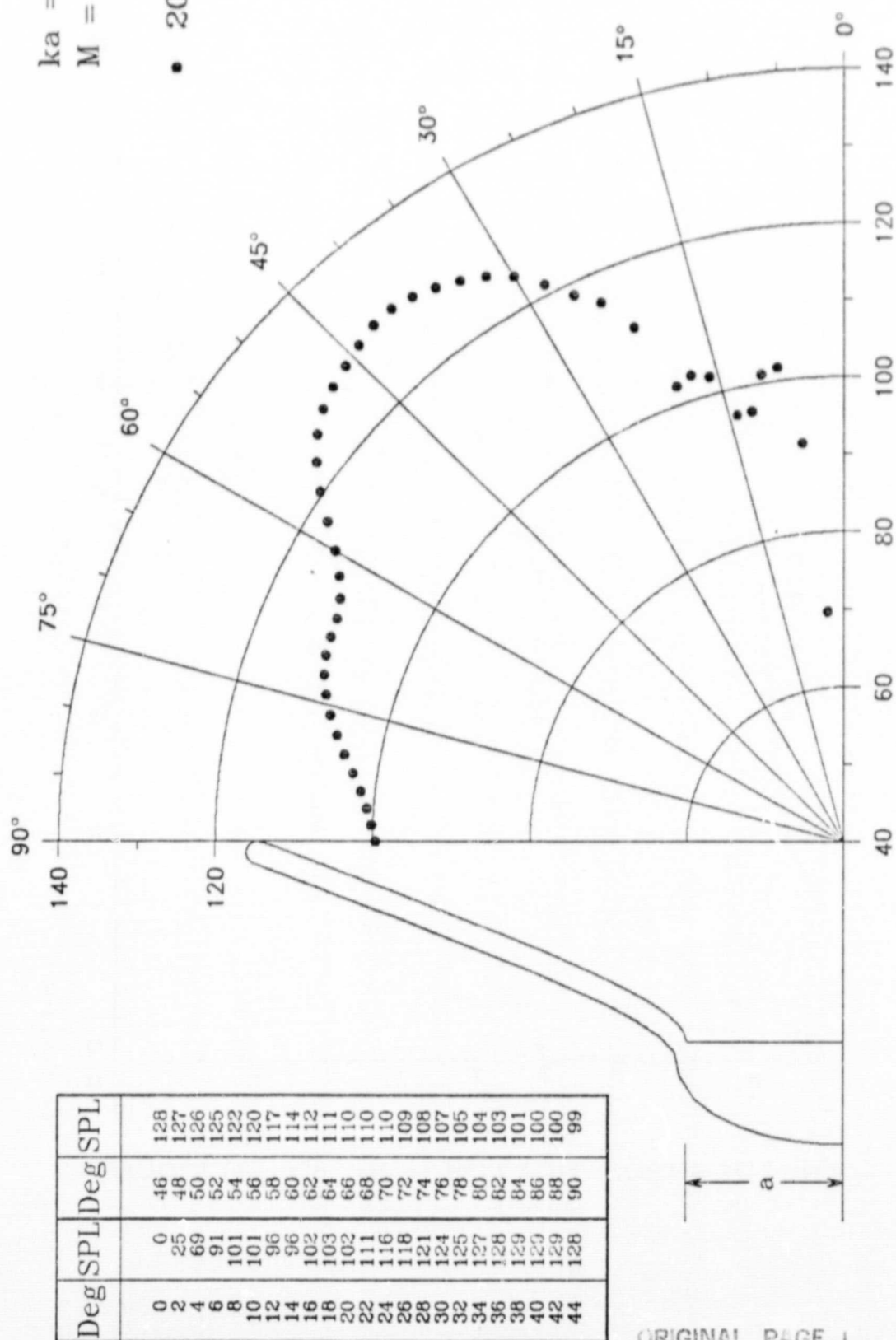


Fig. 62 SPL (dB)

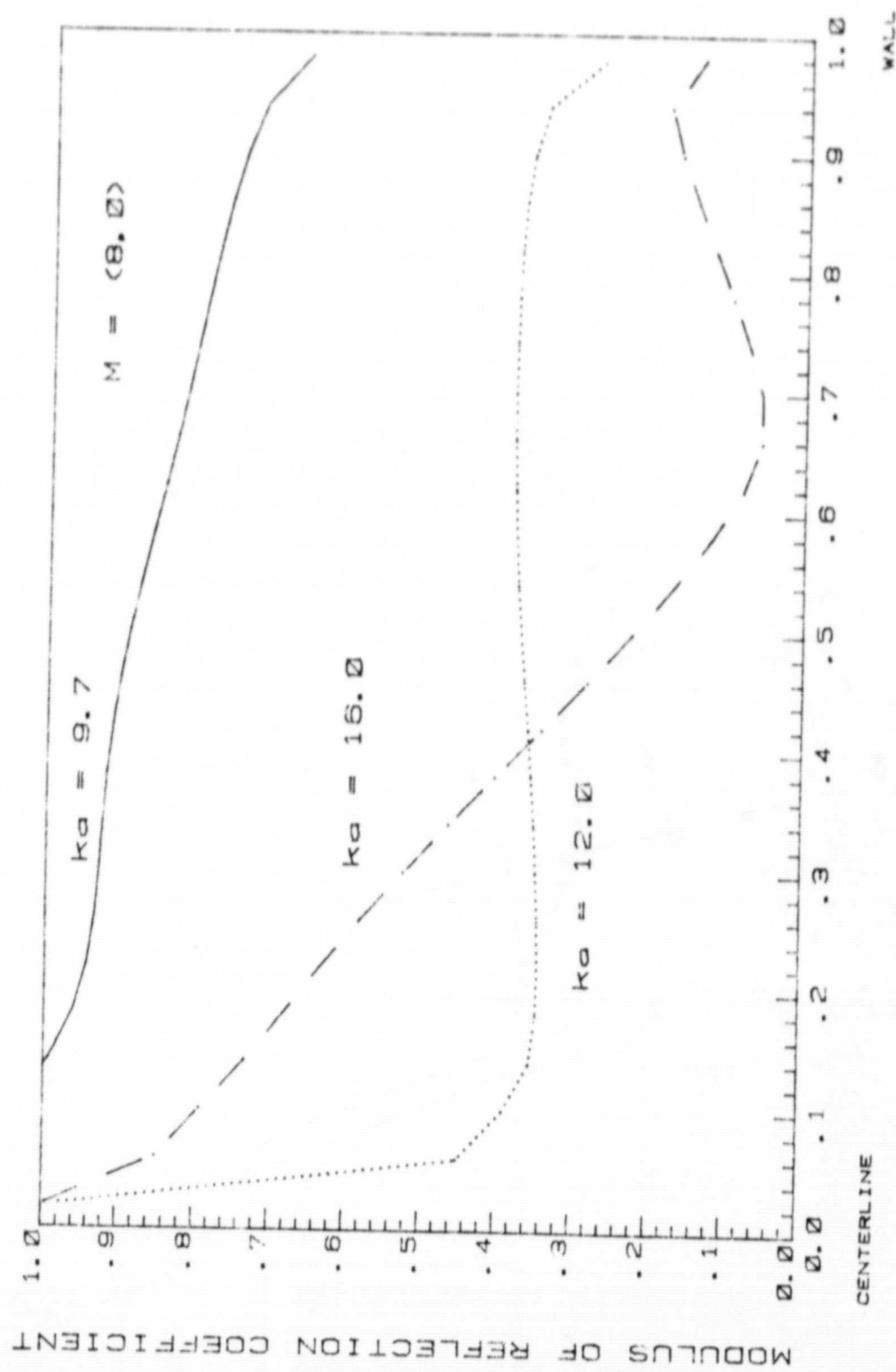
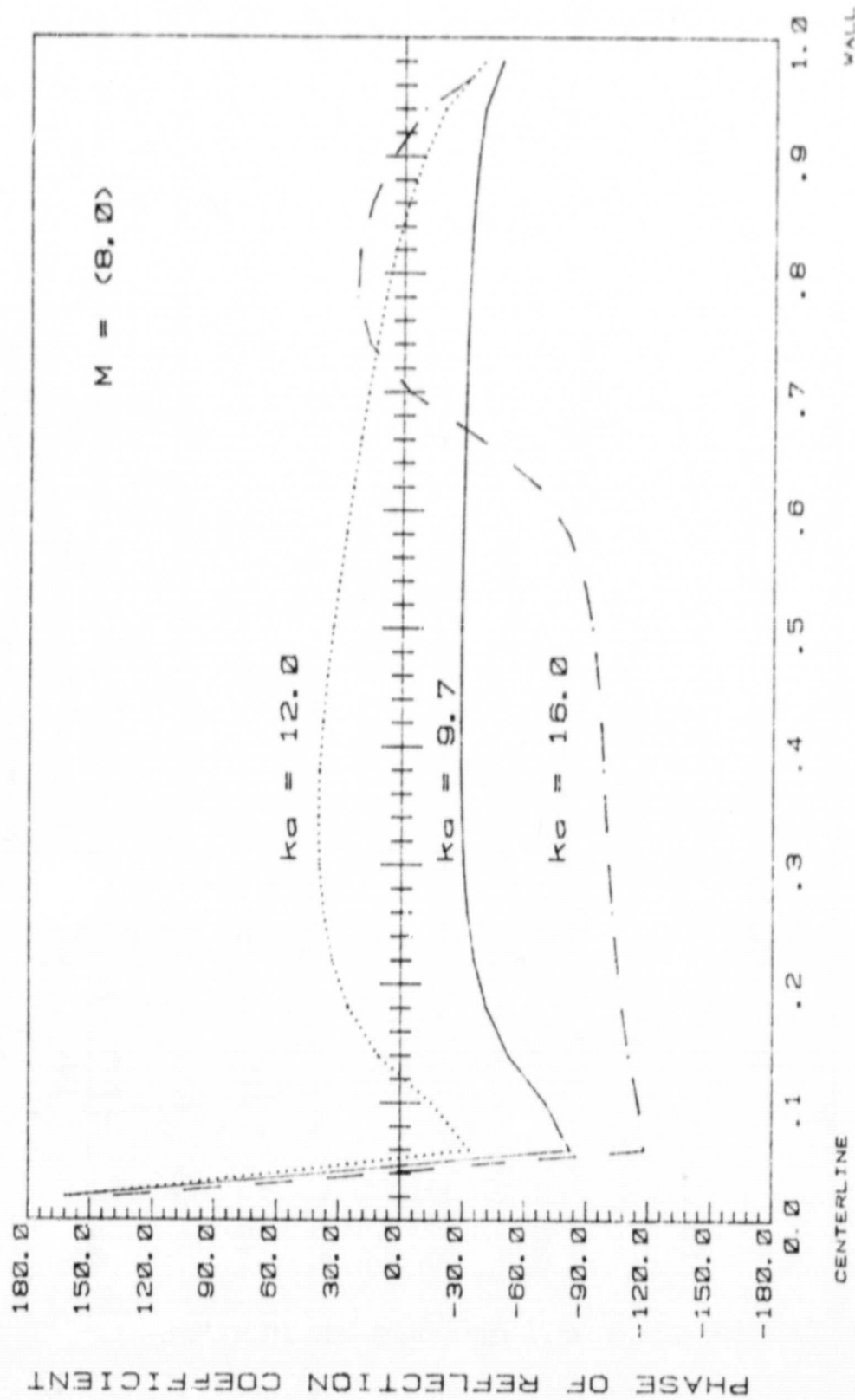


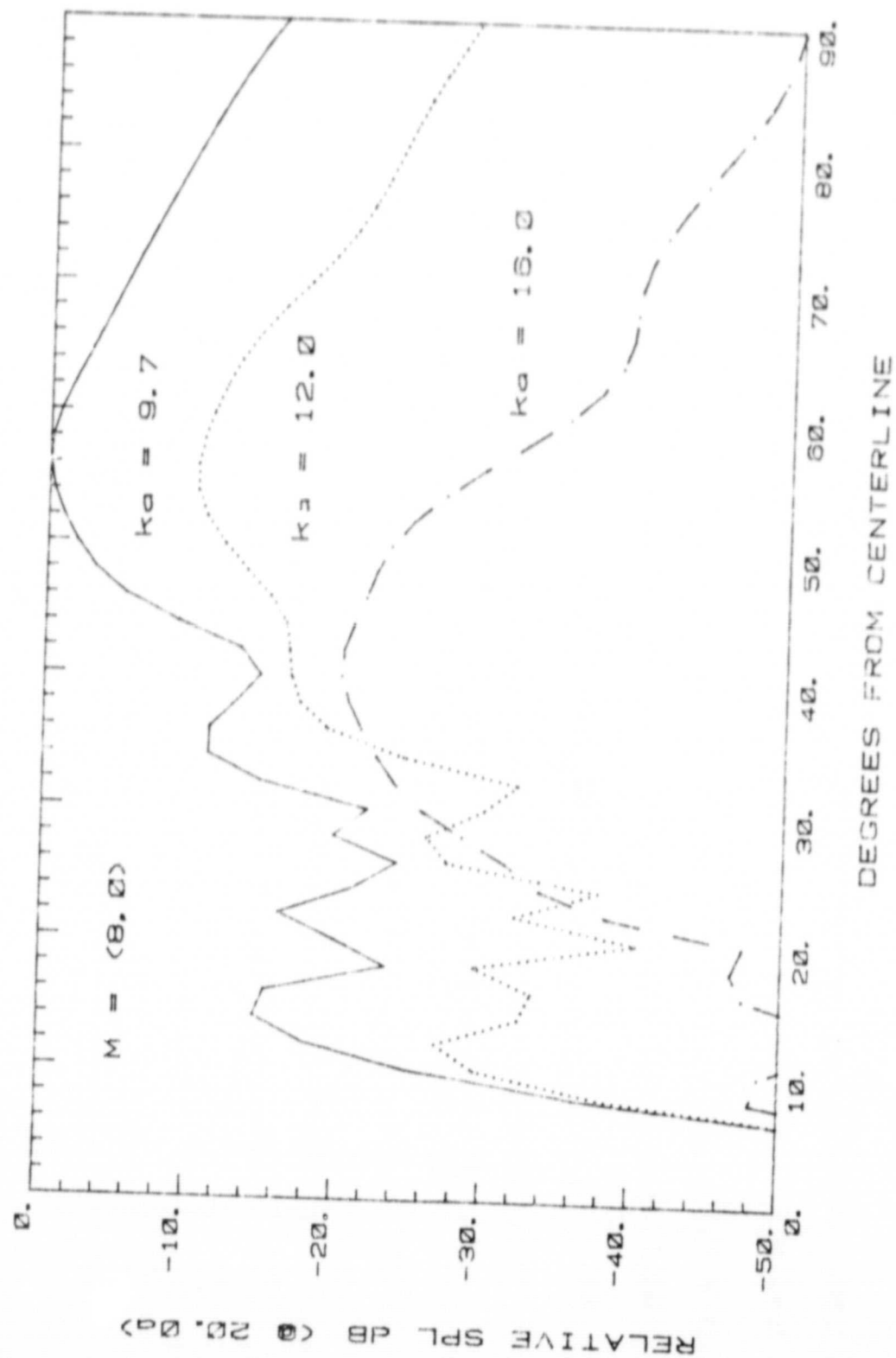
Fig. 63

70° HYPERBOLOIDAL INLET (Exit Plane)



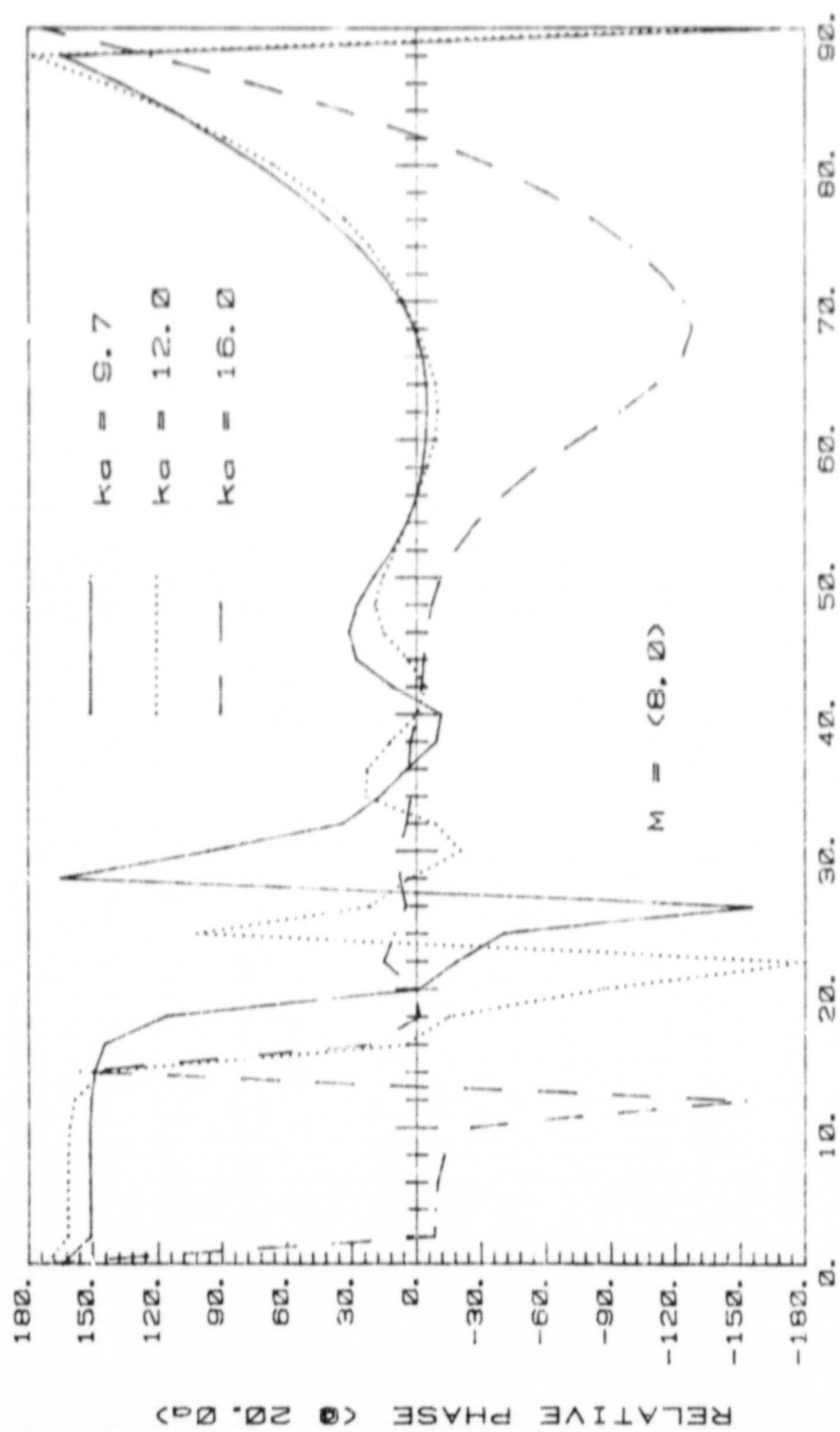
70° HYPERBOLOIDAL INLET (Exit Plane)

Fig. 64

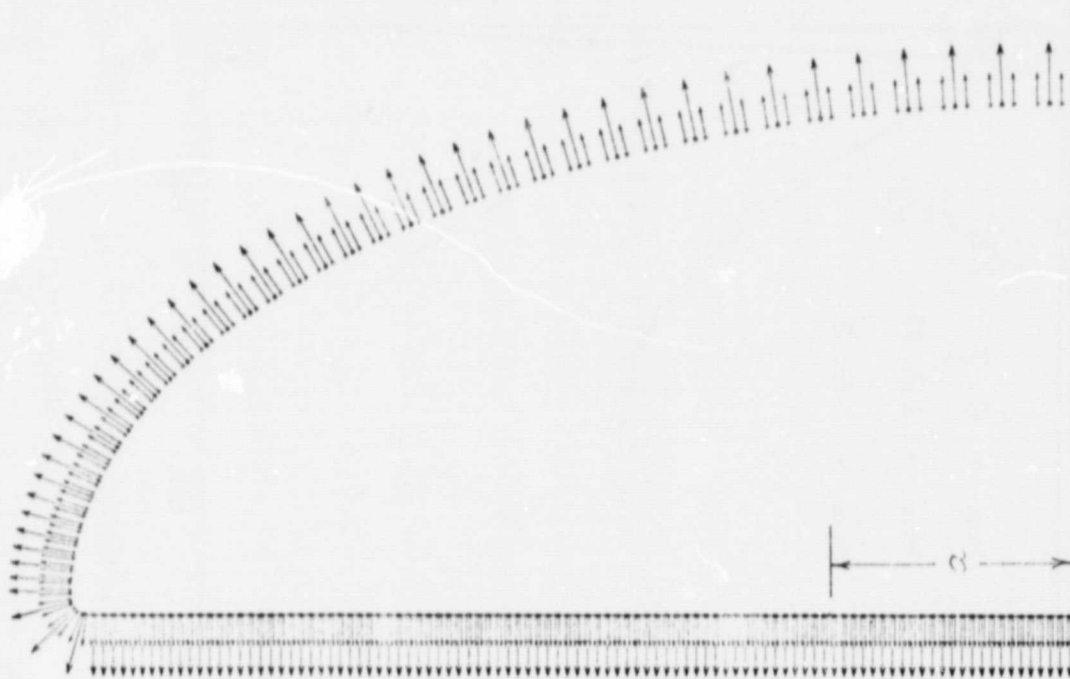


70° HYPERBOLOIDAL INLET

Fig. 65



70° HYPERBOLOIDAL INLET



PLANE BAFFLE
 Geometry From: JSV (1980)69(3), 405-425
 144 pls.

Fig. 67 Plane Baffle Geometry used for Computer Calculations.

PLANE BAFFLE

$ka = 1.00$
 $M = 0$

• 20.00a

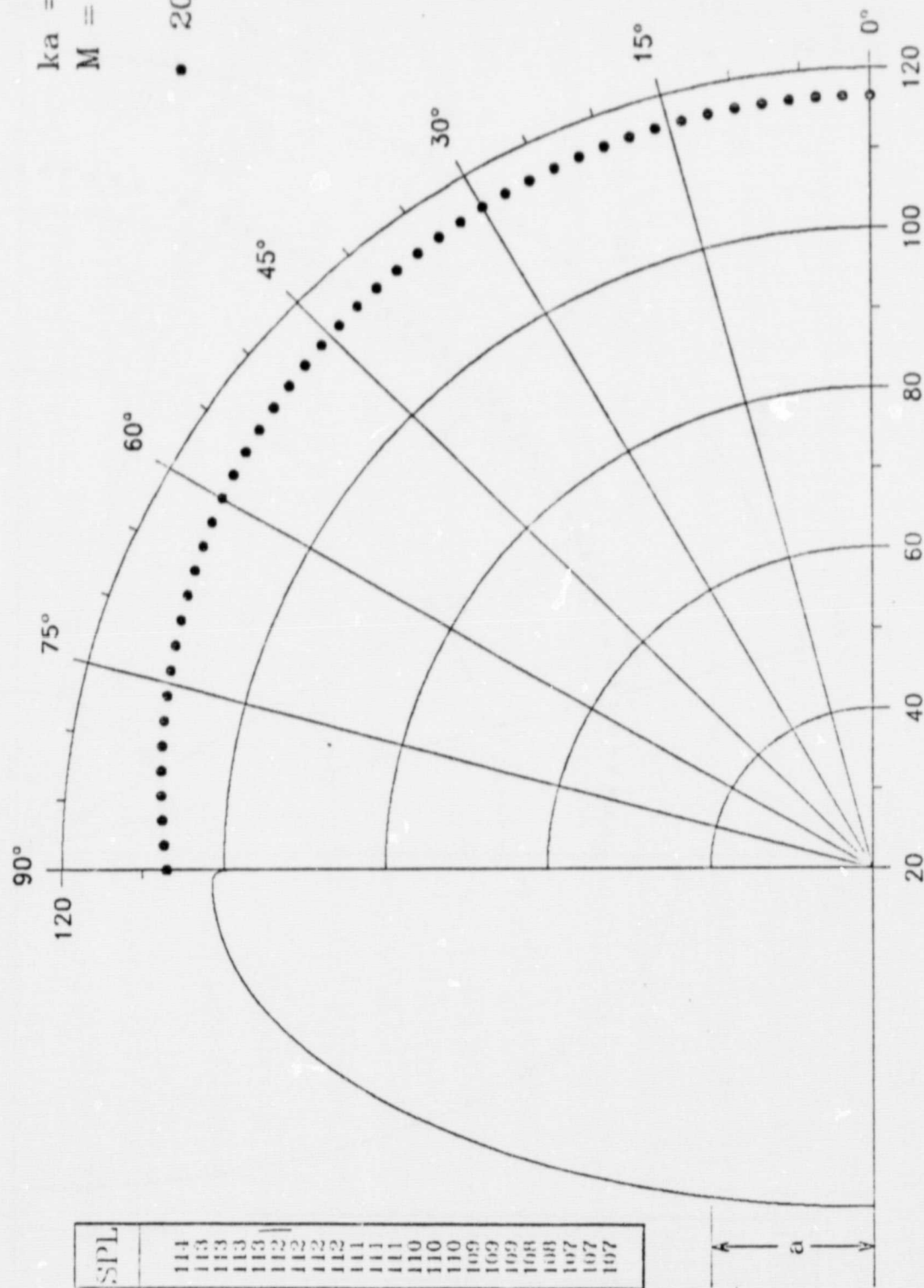


Fig. 68 SPL (dB)

PLANE BAFFLE

$$ka = 2.00$$
$$\mathbf{M} = \mathbf{0}$$

• 20.00a

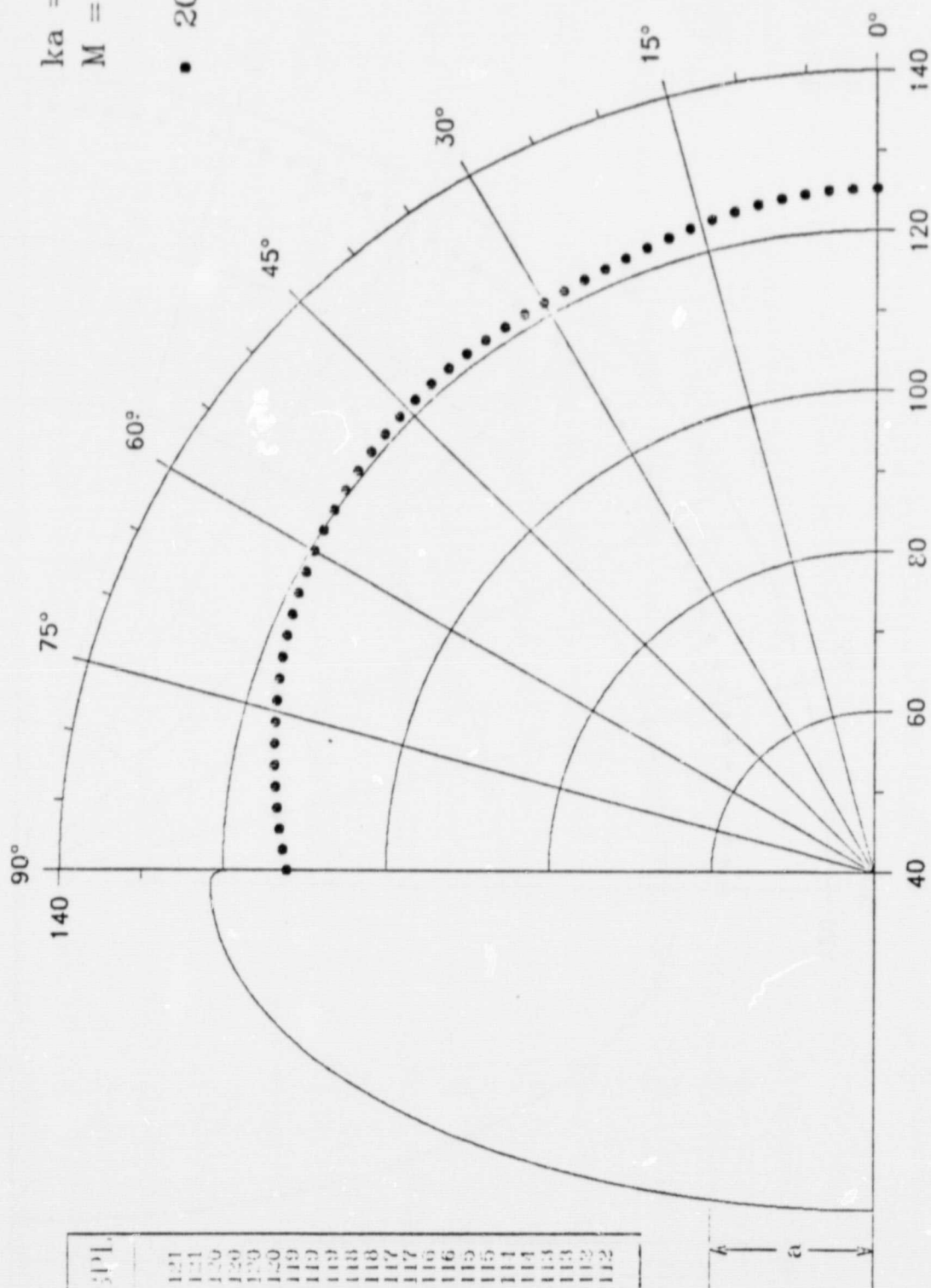


Fig. 69 SPL (dB)

Deg	SPL	deg SPL
0	115	121
2	116	121
4	116	120
6	121	120
8	121	120
10	121	120
12	121	119
14	123	119
16	123	119
18	122	118
20	122	118
22	122	117
24	122	117
26	121	116
28	121	116
30	121	115
32	121	115
34	121	114
36	121	114
38	121	113
40	121	113
42	121	112
44	121	112

ORIGINAL PAGE IS
OF POOR QUALITY

PLANE BAFFLE

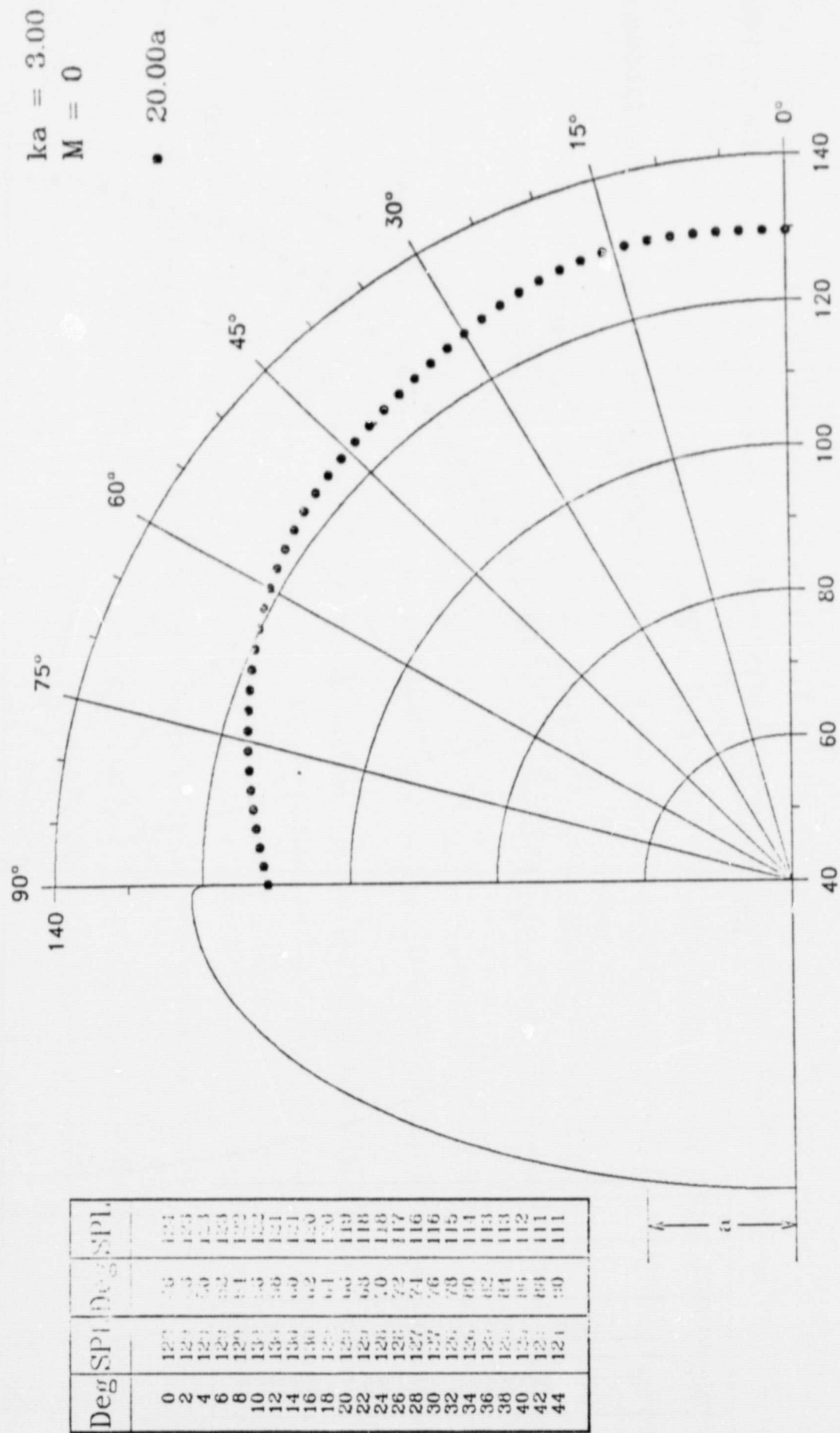


Fig. 70 SPL (dB)

PLANE BAFFLE

$ka = 3.83$

$M = 0$

• 20.00a

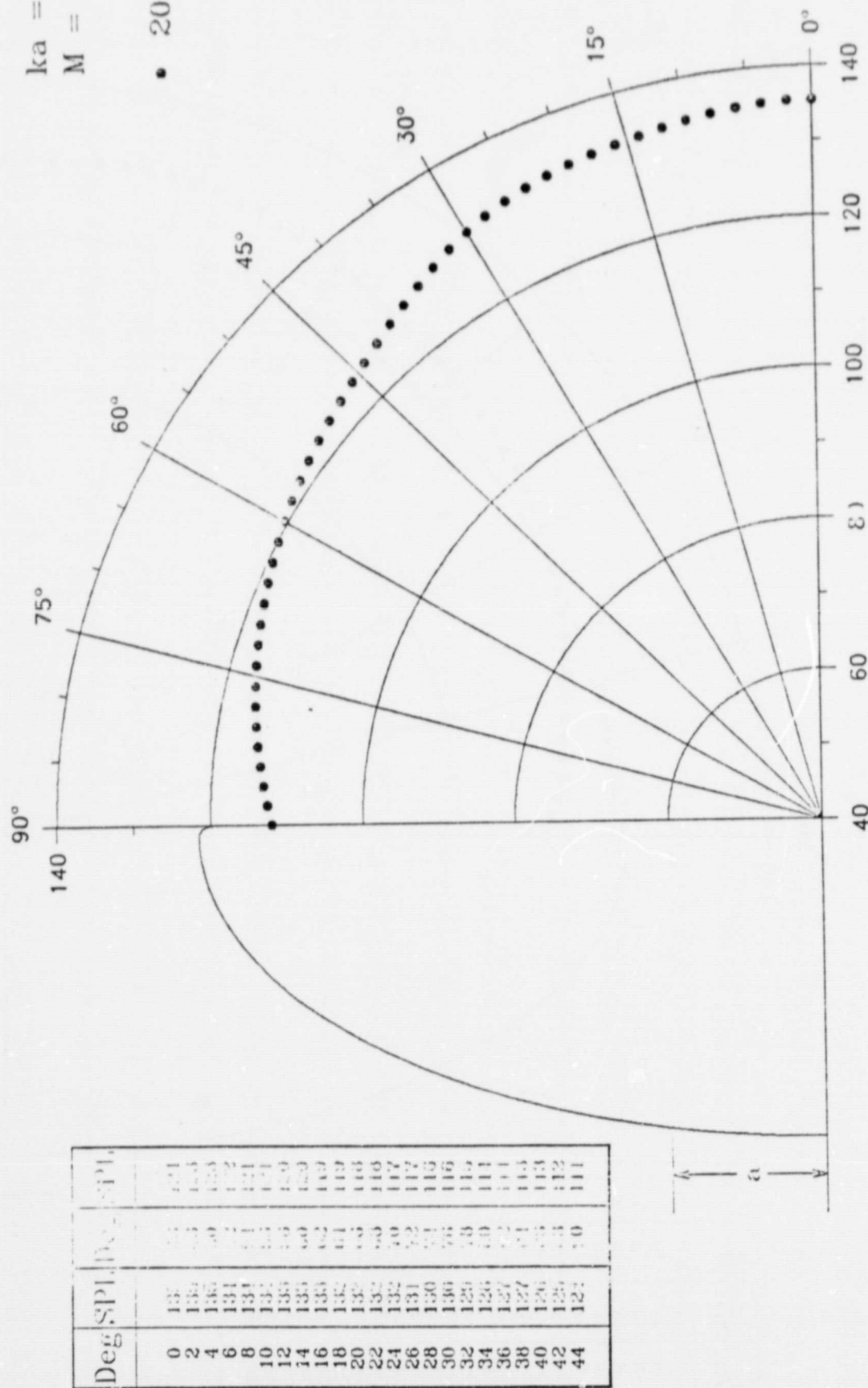
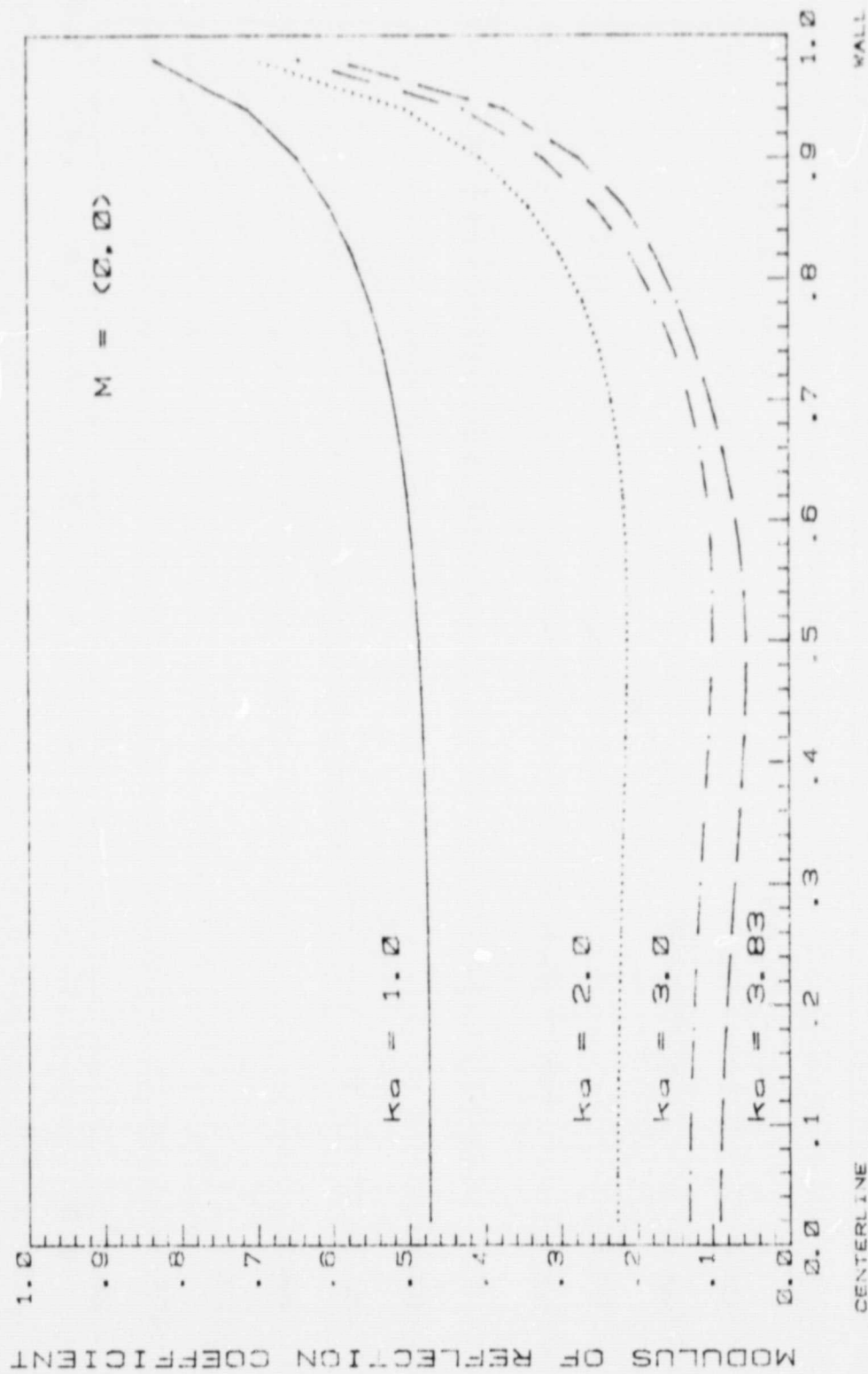
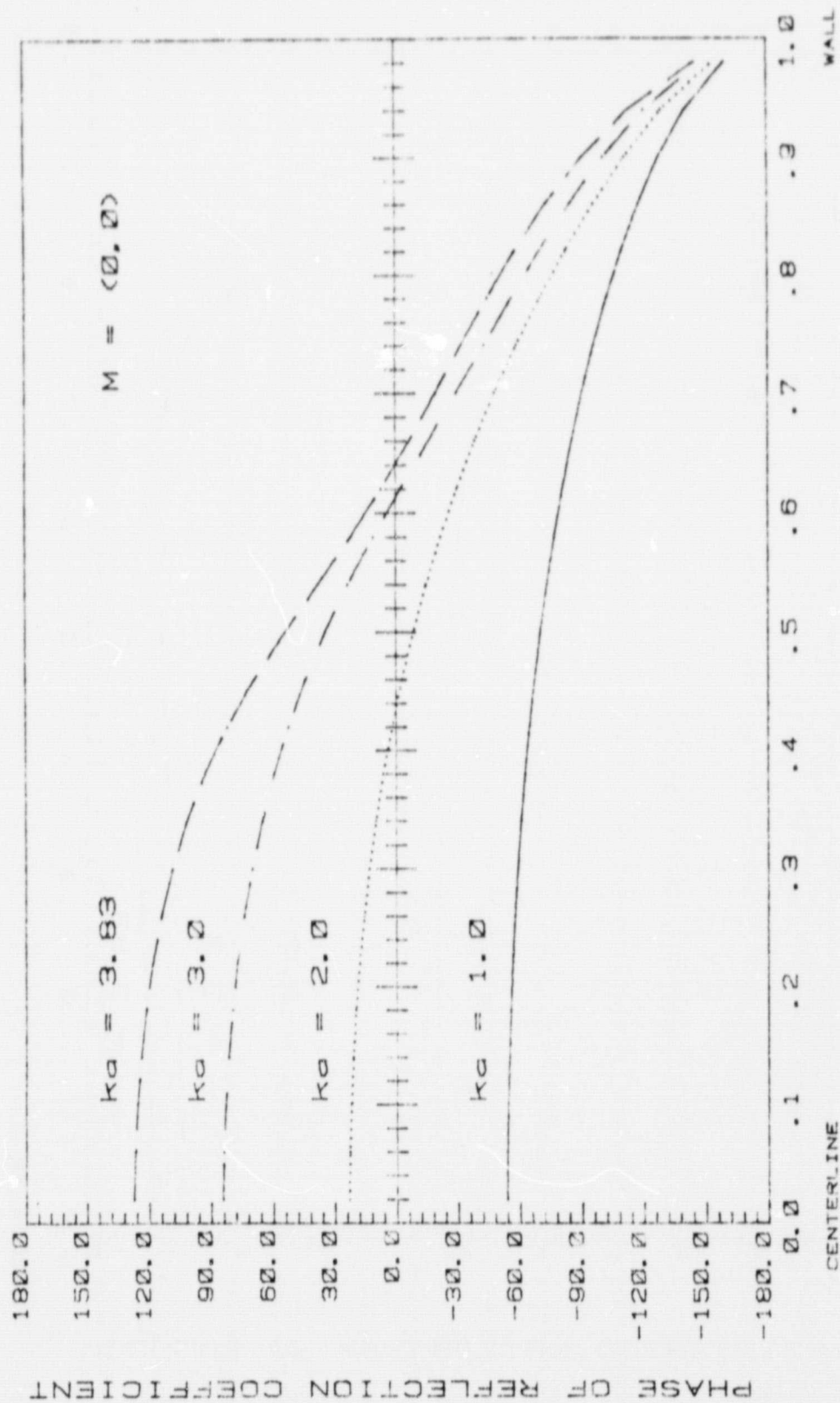


Fig. 71 SPL (dB)



PLANE BAFFLE

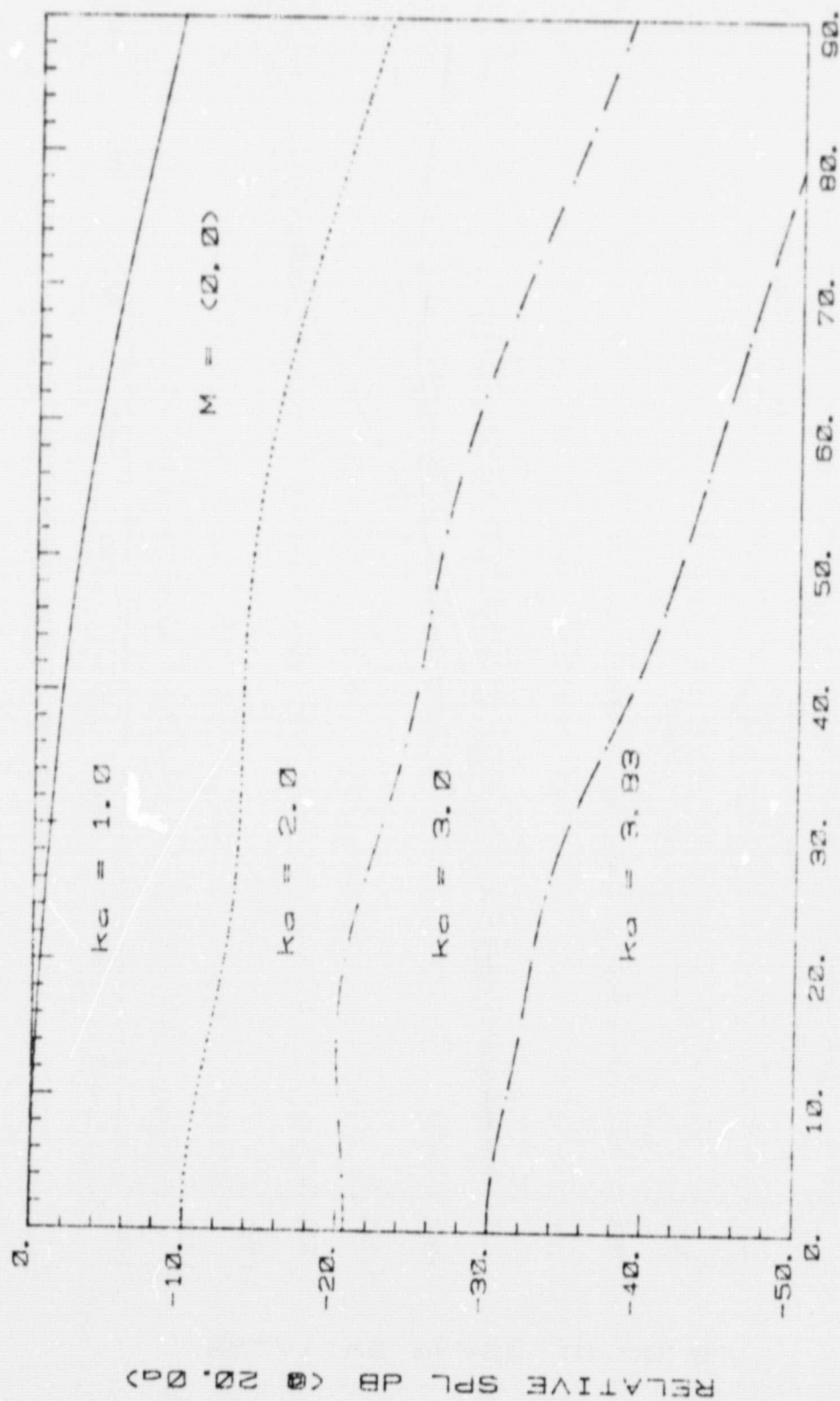
Fig. 72



PLANE BAFFLE

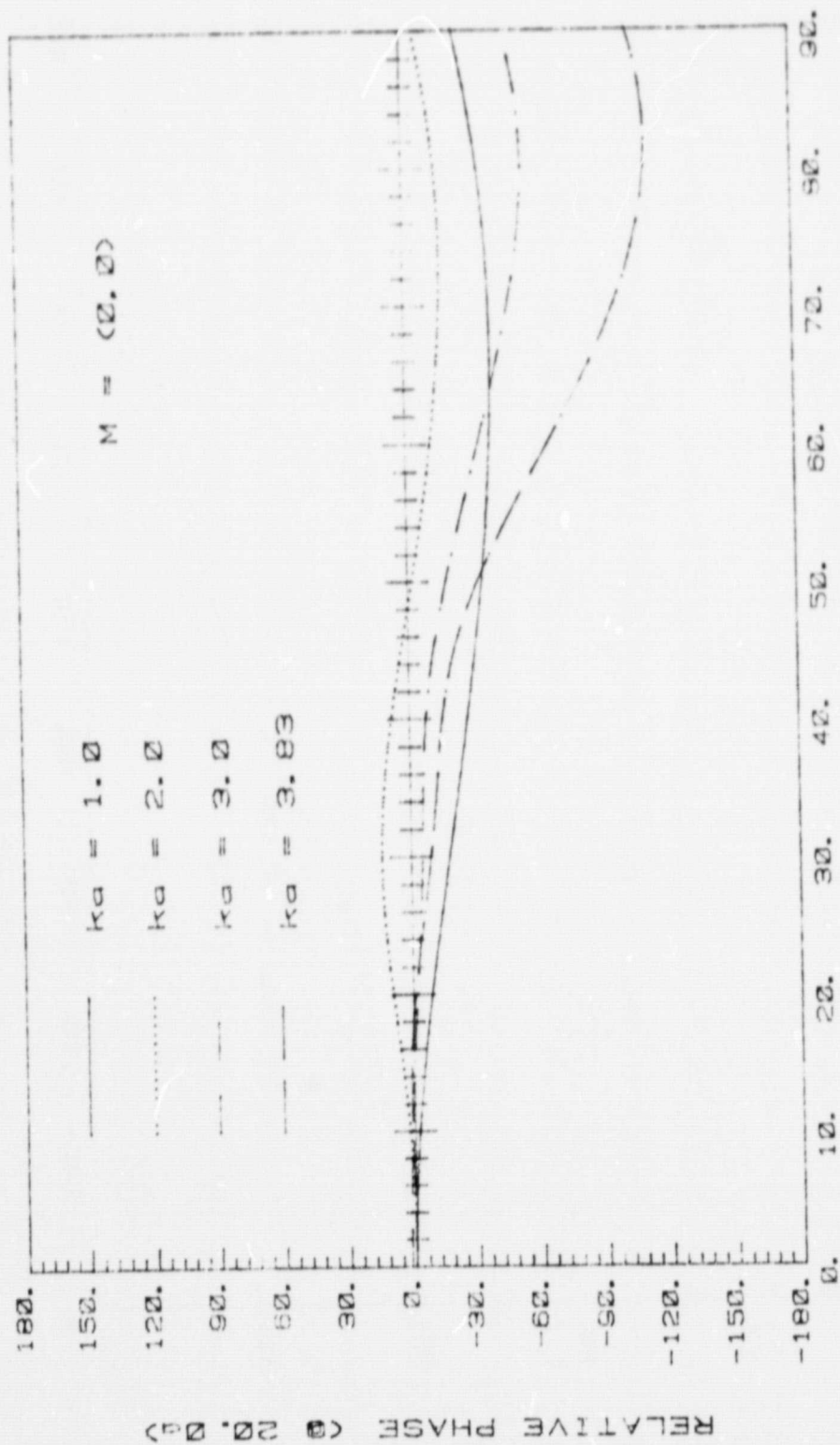
Fig. 73

ORIGINAL PAGE IS
OF POOR QUALITY



PLANE BAFFLE

Fig. 74



PLANE BAFFLE

Fig. 75

PLANE BAFFLE

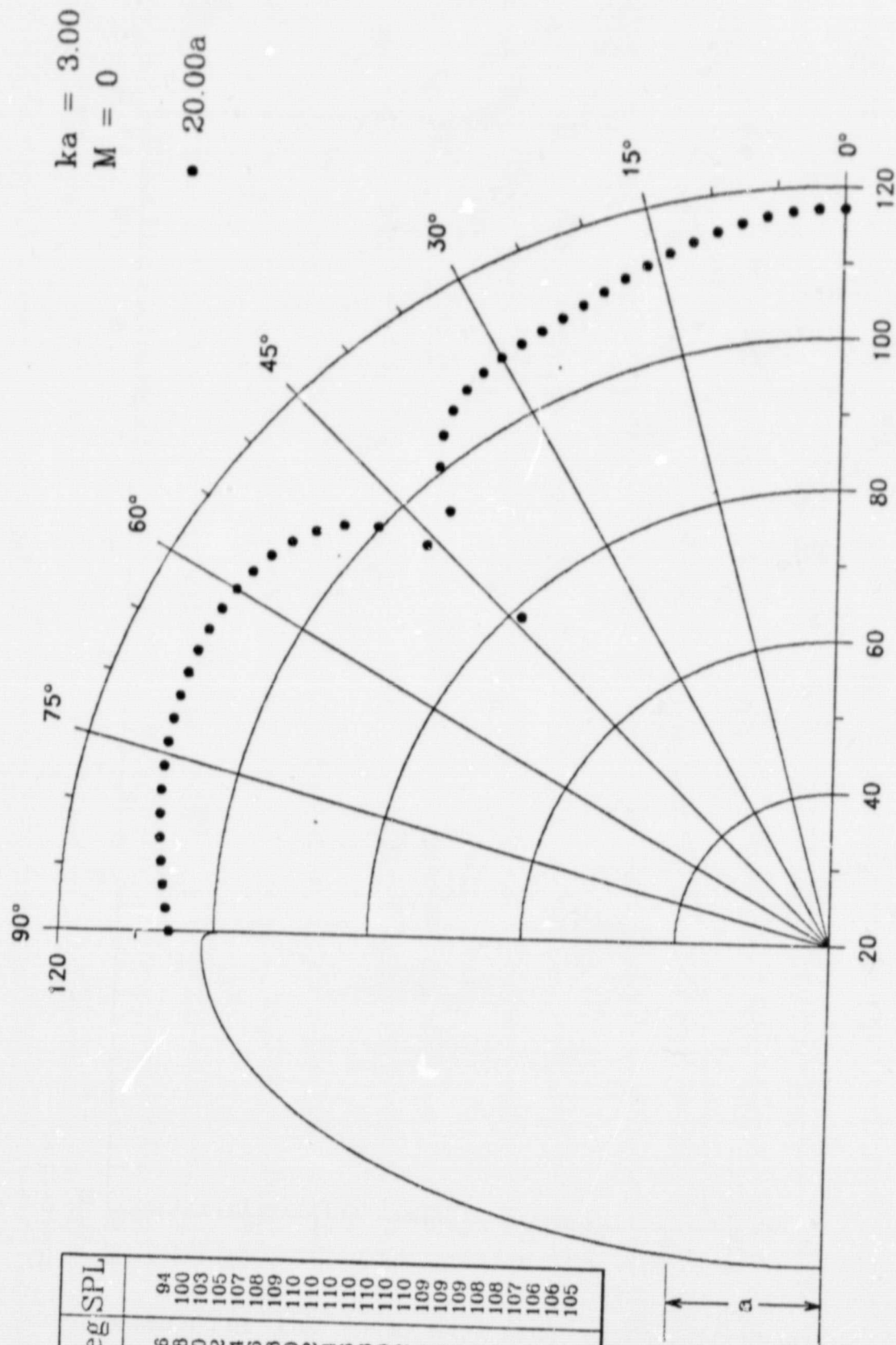
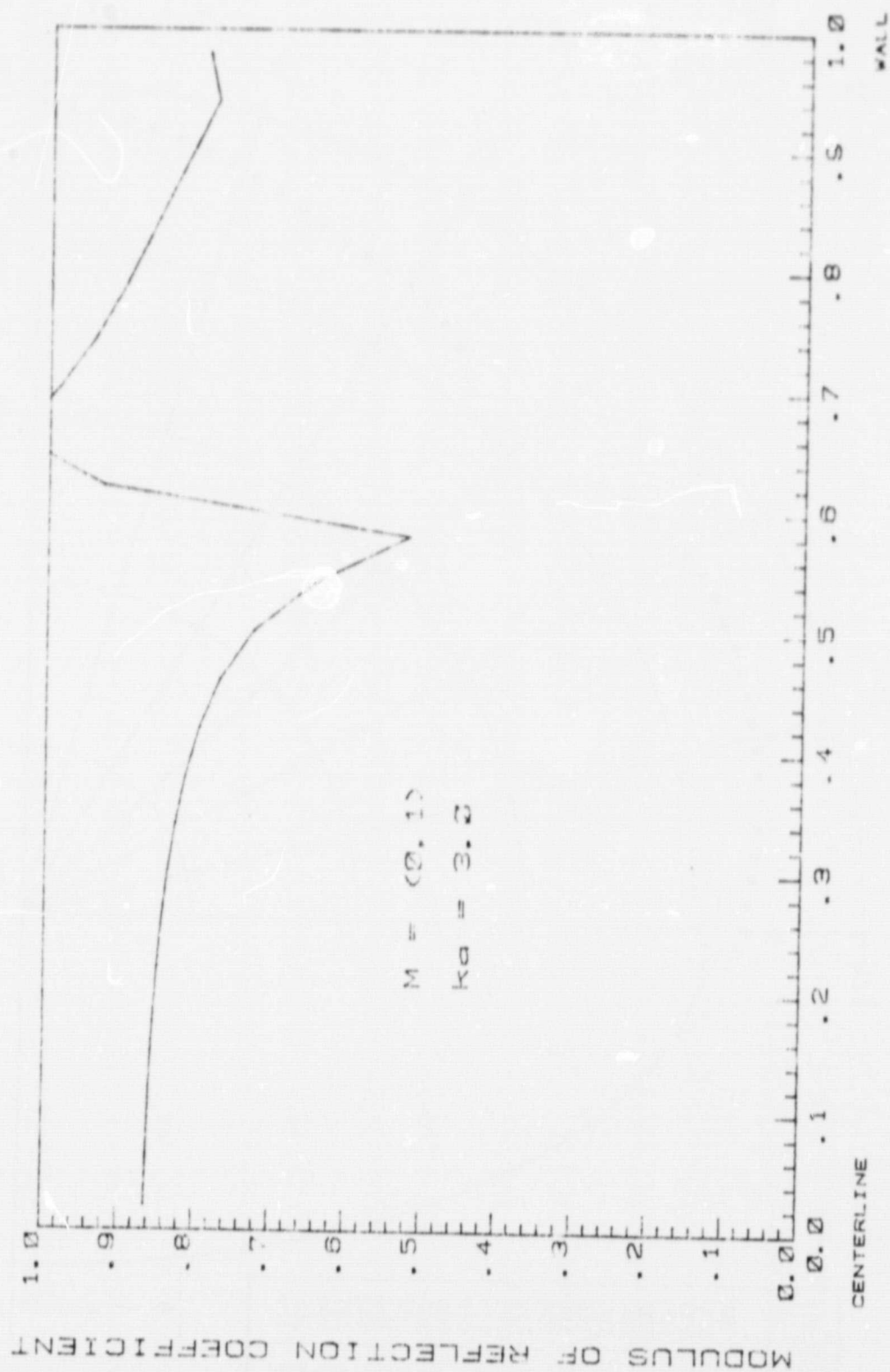
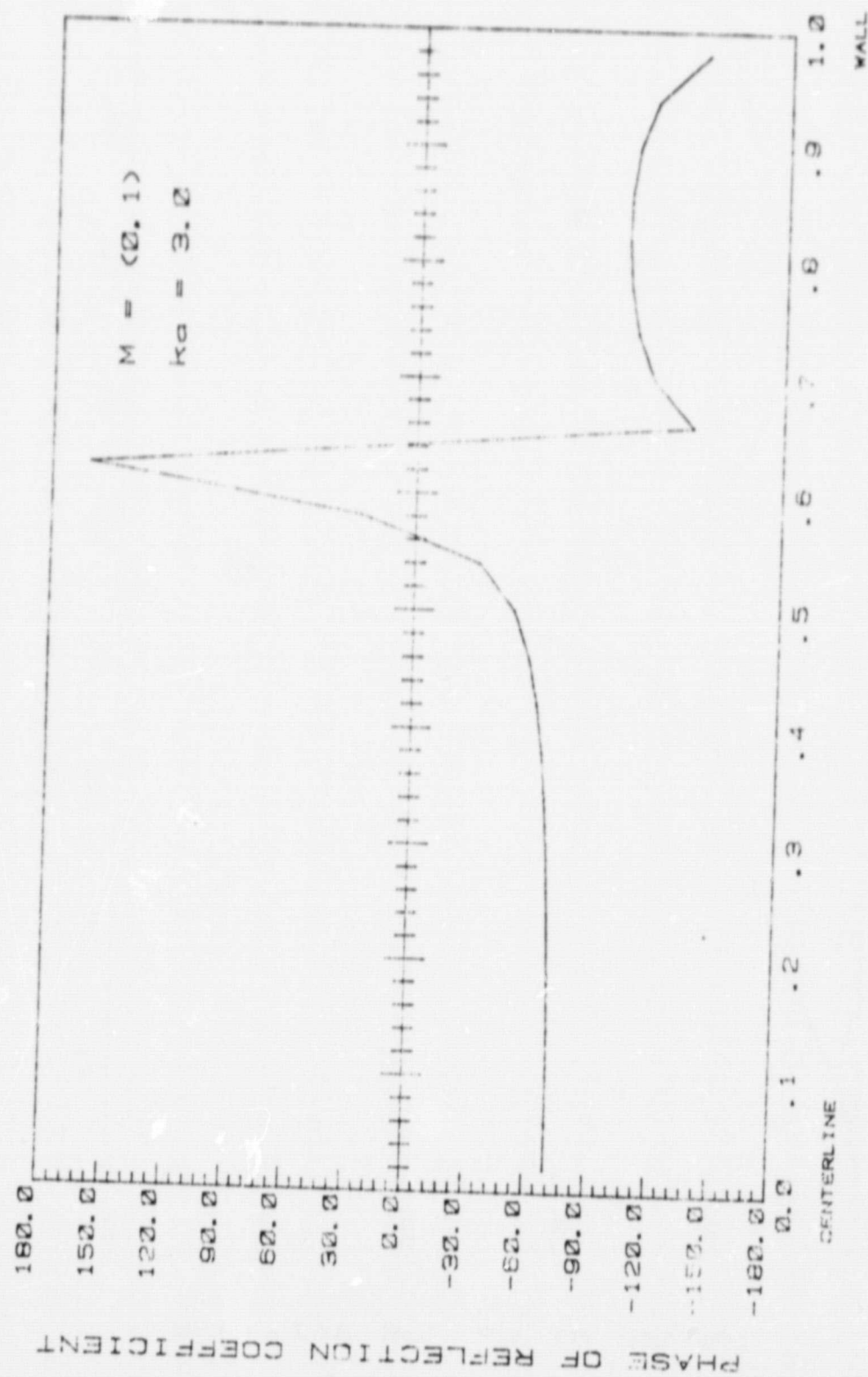


Fig. 76 SPL (dB)



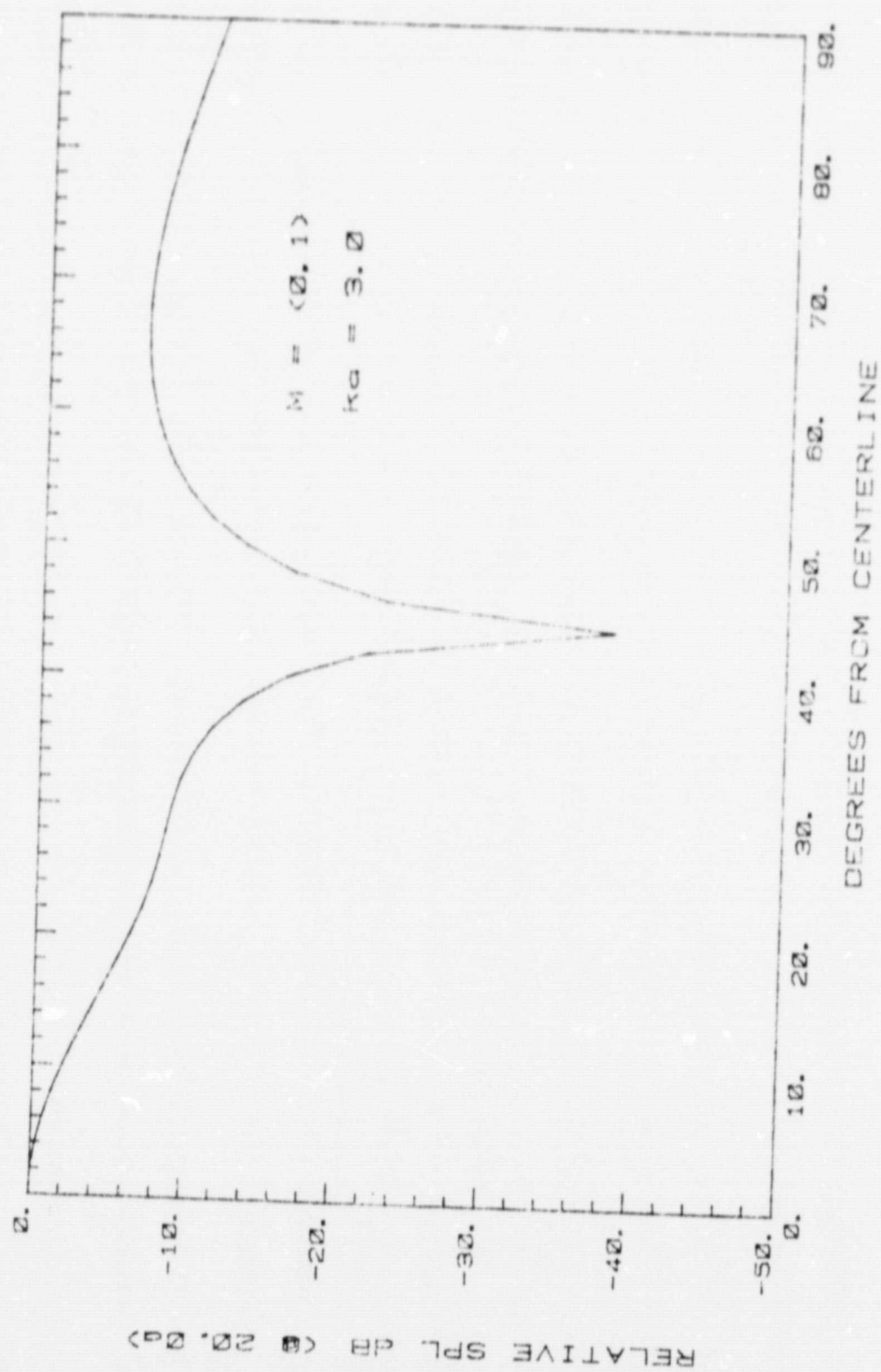
PLANE BAFFLE

Fig. 77



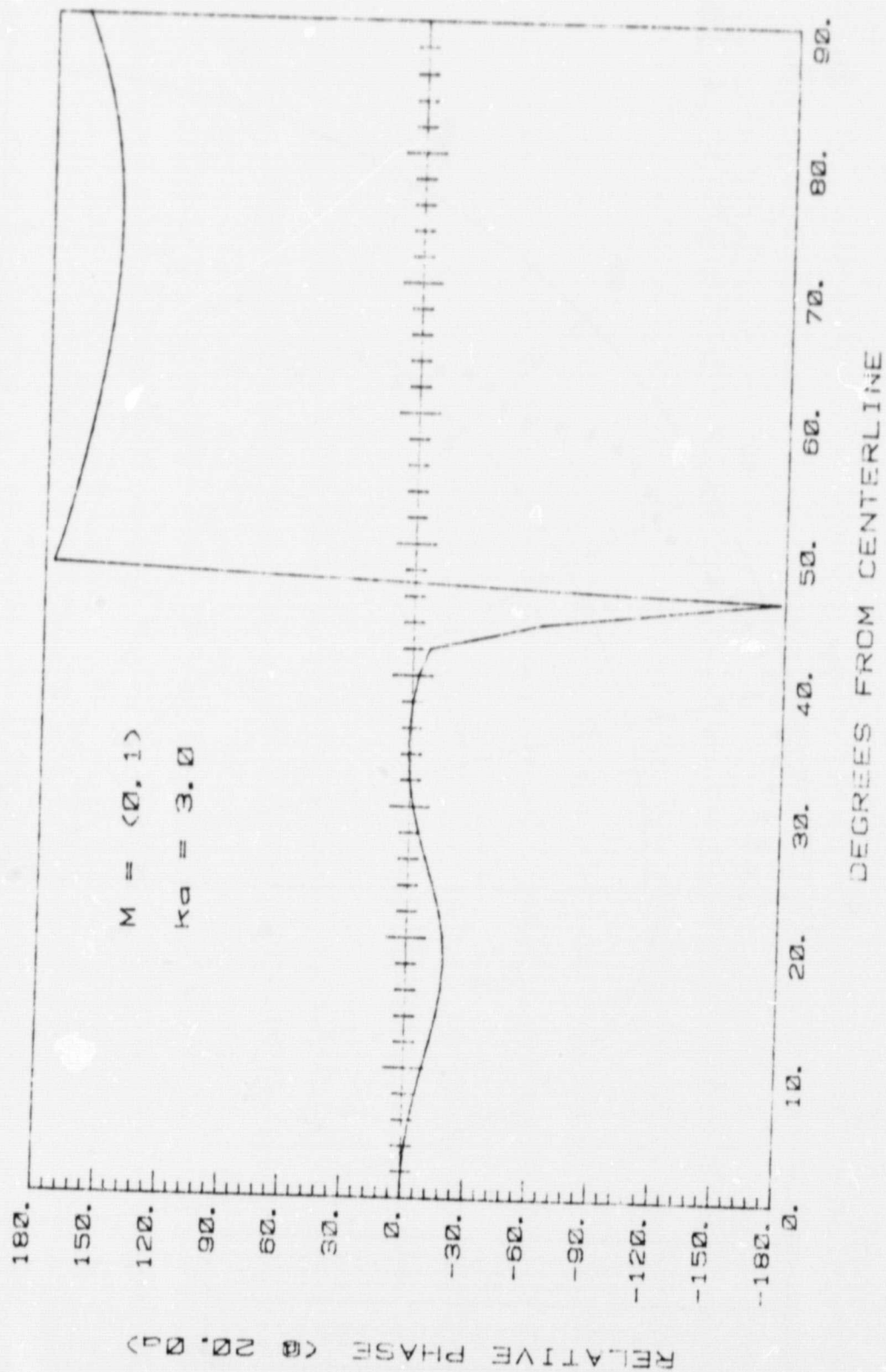
PLANE BAFFLE

Fig. 78



PLANE BAFFLE

Fig. 79



PLANE BAFFLE

Fig. 80

PLANE BAFFLE

$ka = 9.70$

$M = 8$

• 20.00a

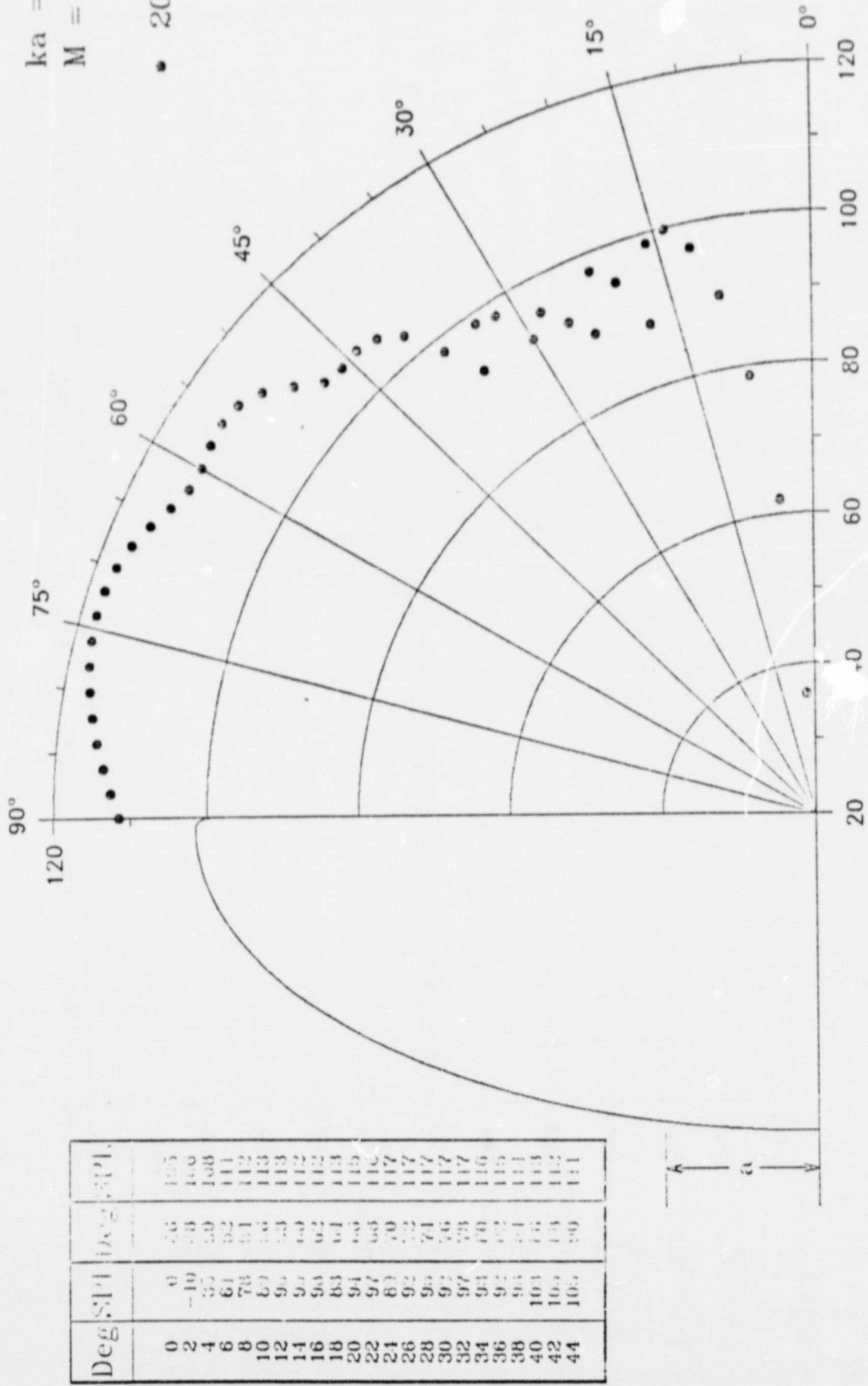


Fig. 81 SPL (dB)

PLANE BAFFLE

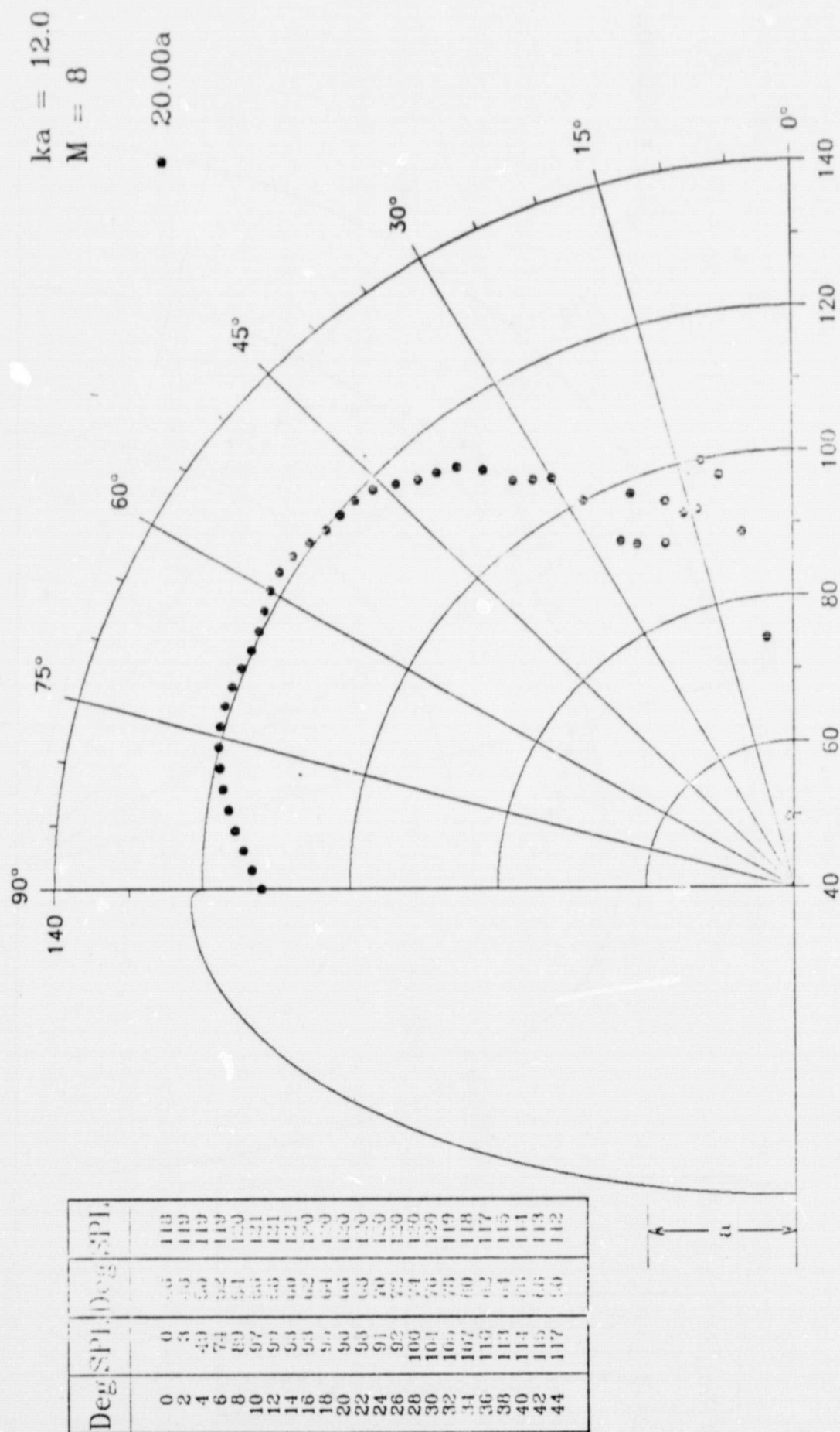


Fig. 82 SPL (dB)

PLANE BAFFLE

$ka = 13.5$

$M = 8$

• 20.00a

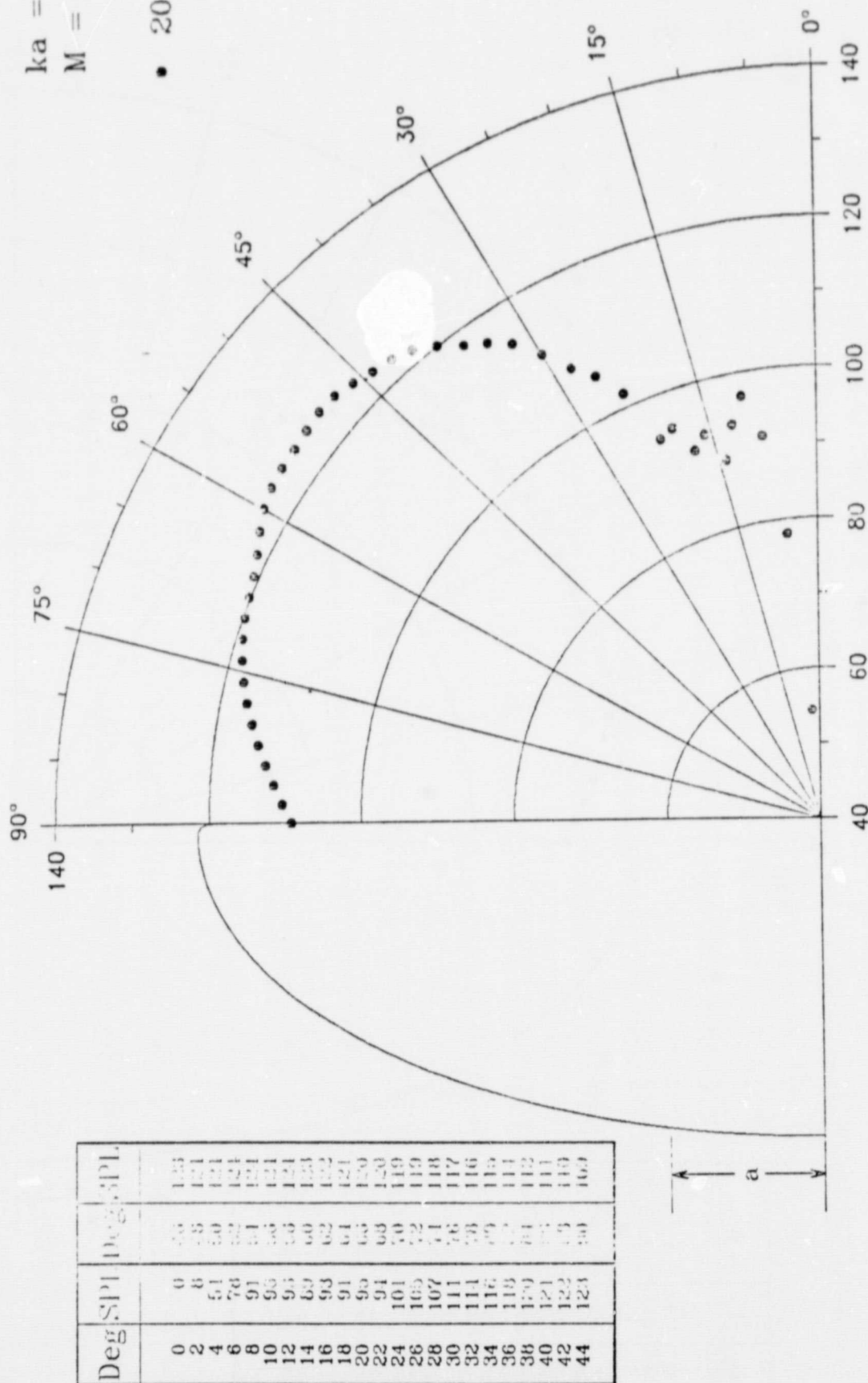


Fig. 83 SPL (dB)

PLANE Baffle

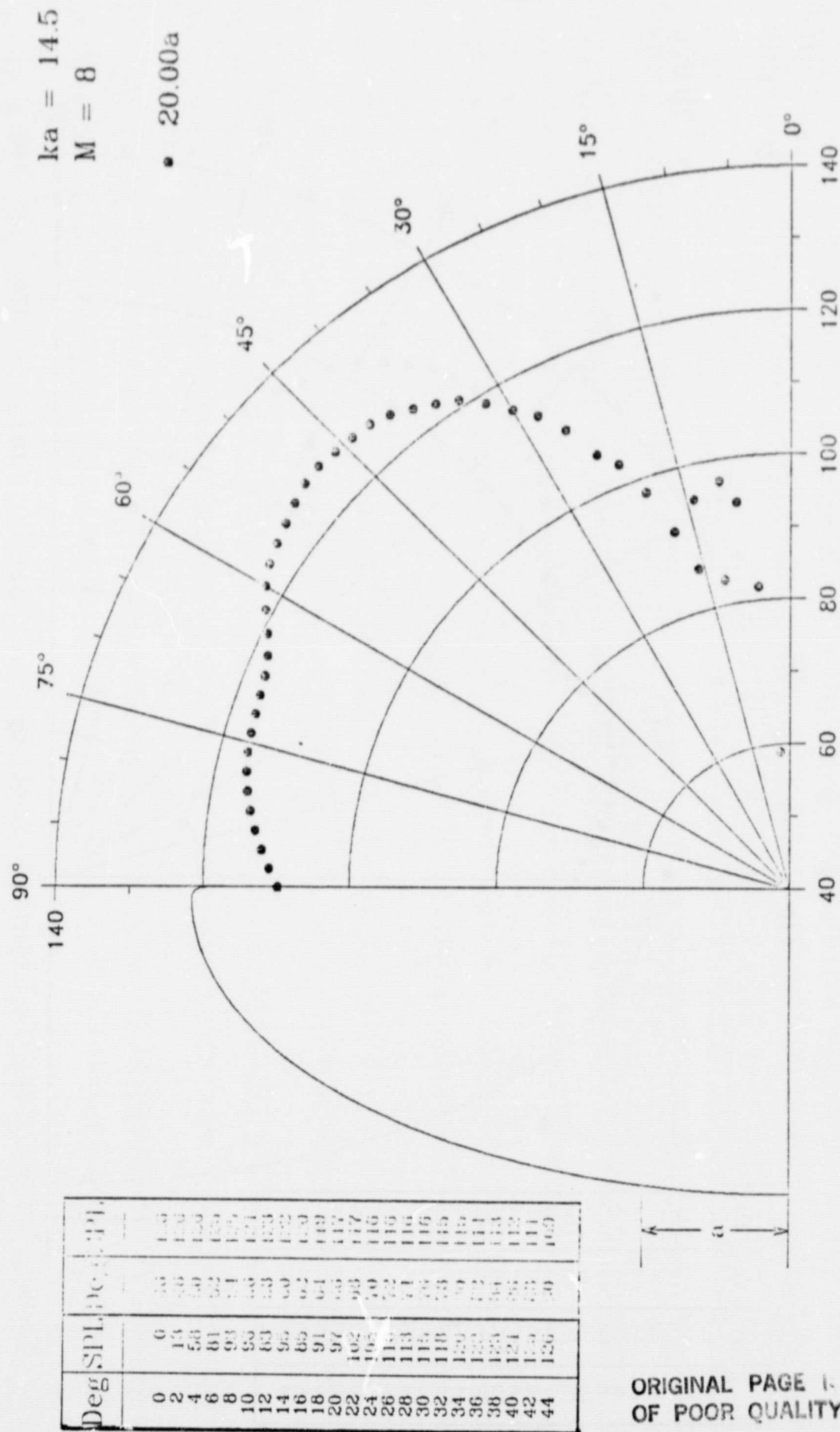


Fig. 84 SPL (dB)

PLANE Baffle

$ka = 16.0$
 $M = 8$

• 20.00a

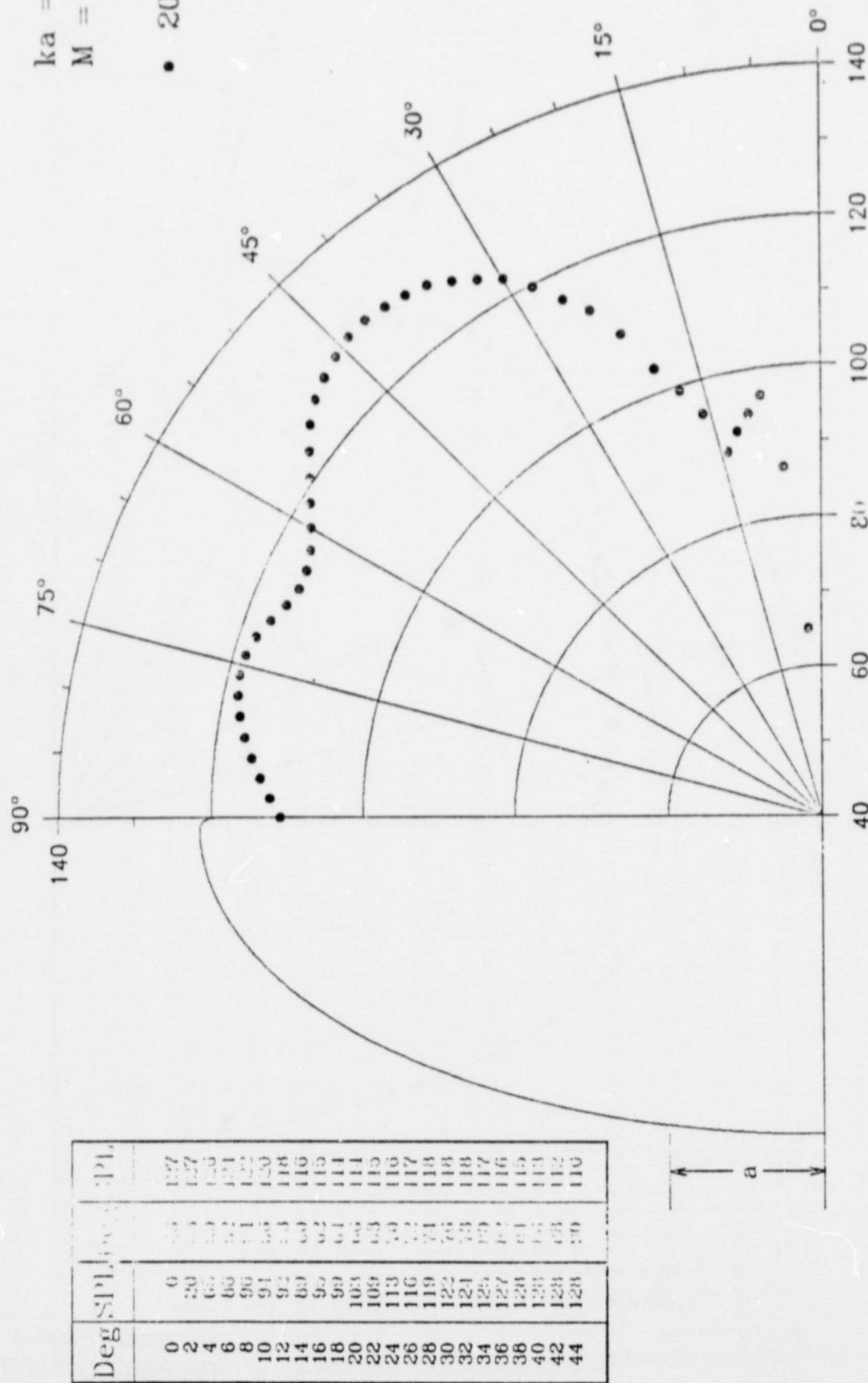
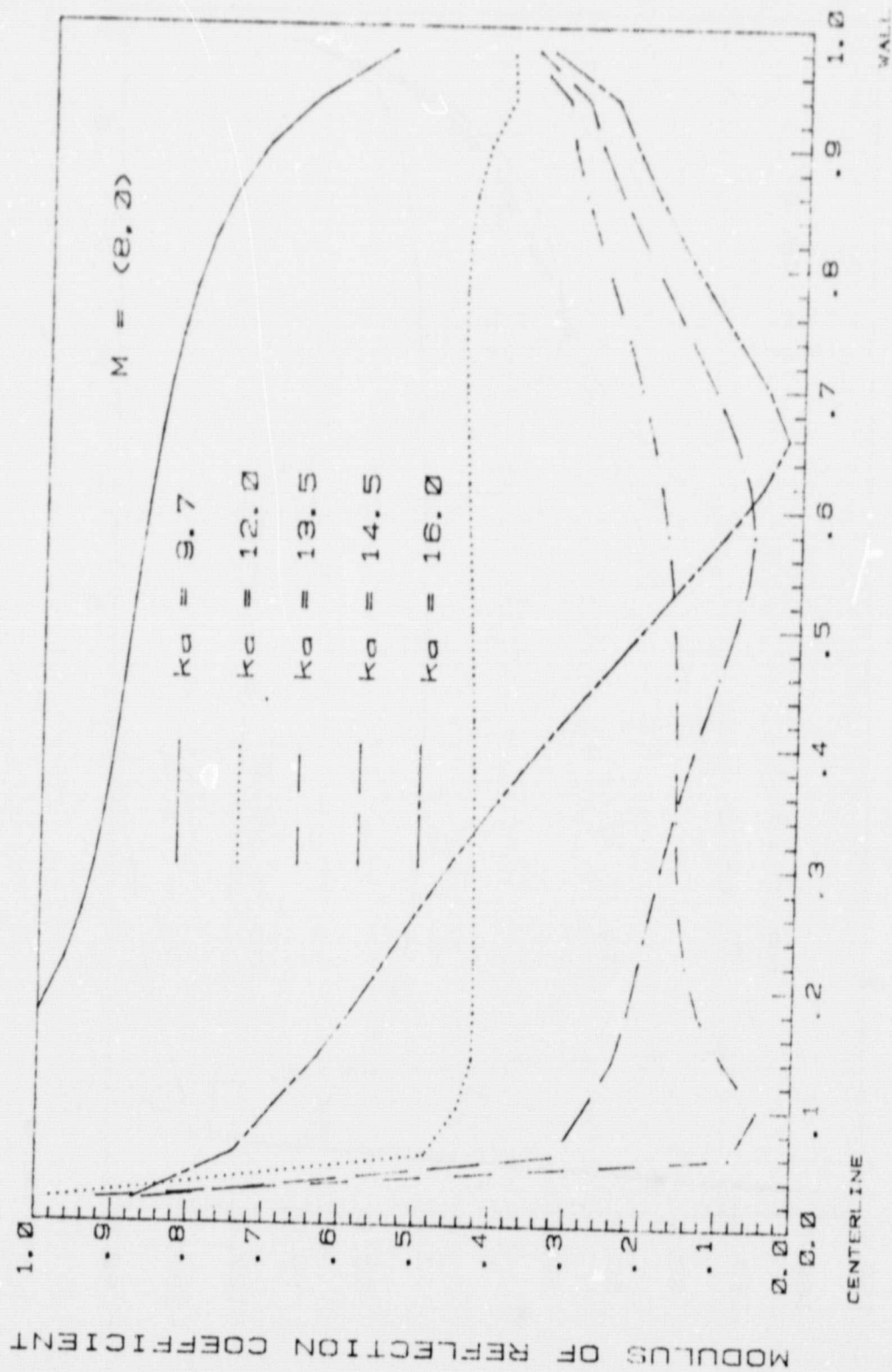
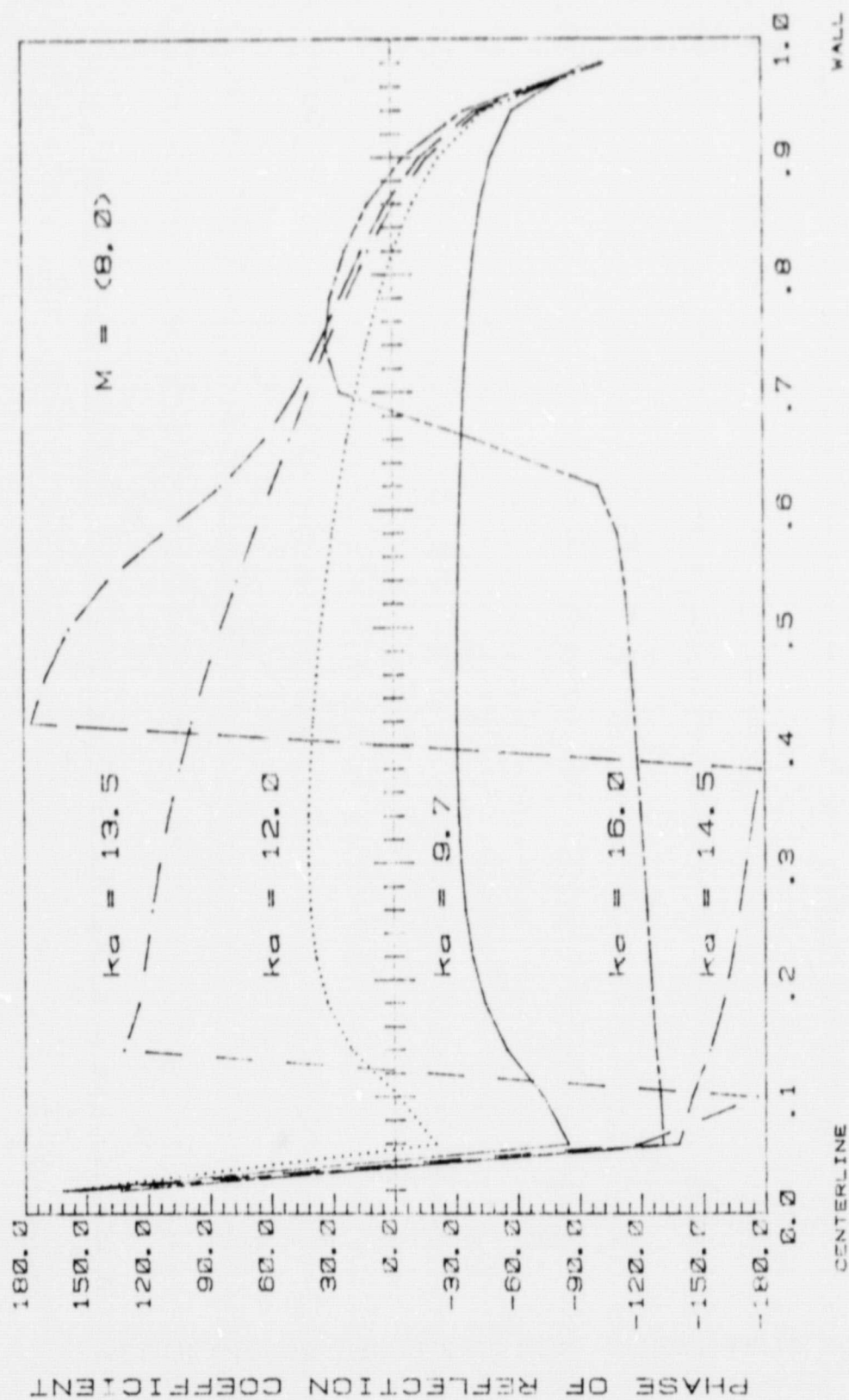


Fig. 85 SPL (dB)



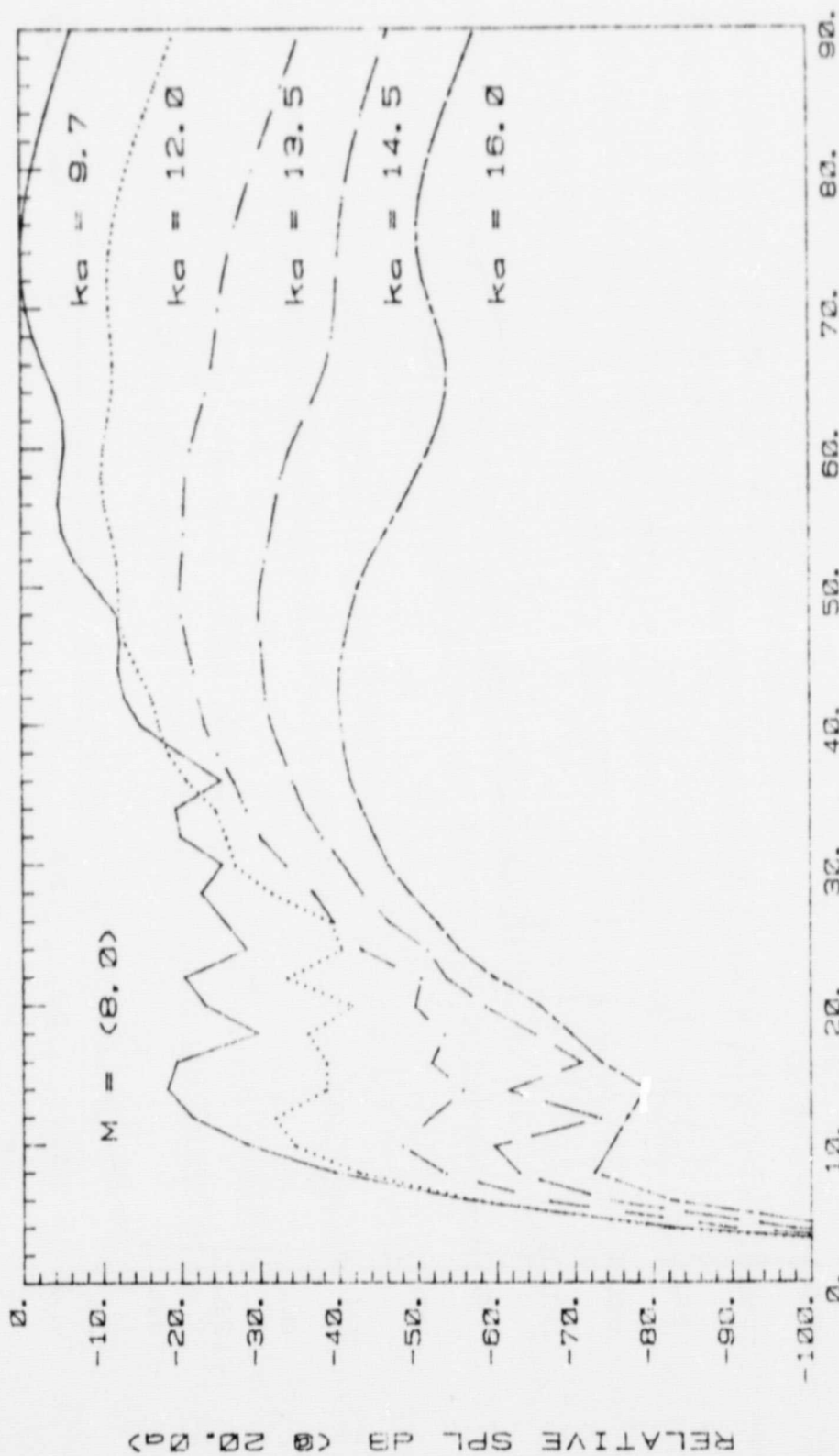
PLANE BAFFLE

Fig. 86



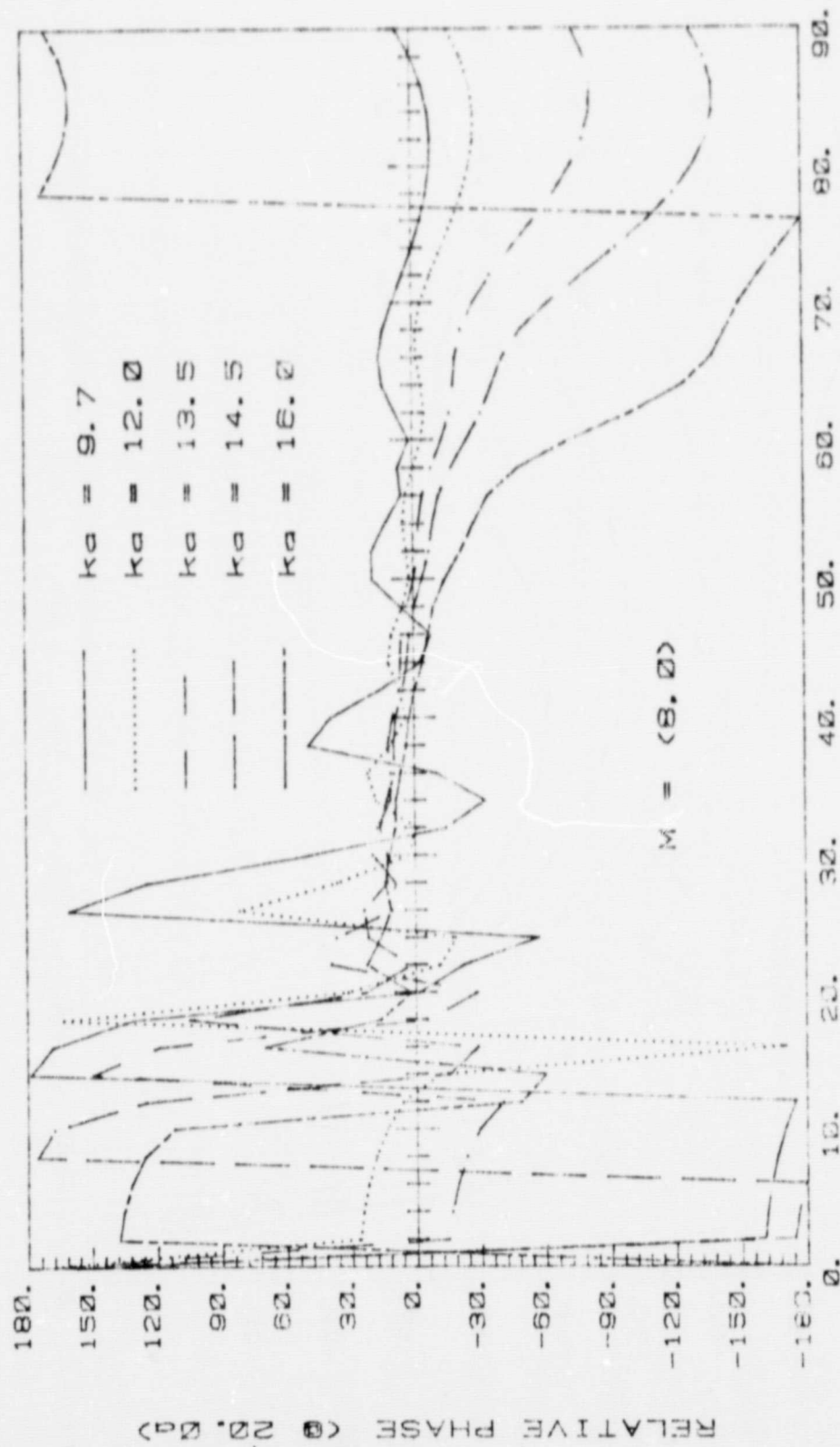
PLANE BAFFLE

Fig. 87



PLANE BAFFLE

Fig. 88



PLANE BAFFLE

Fig. 89

PLANE BAFFLE

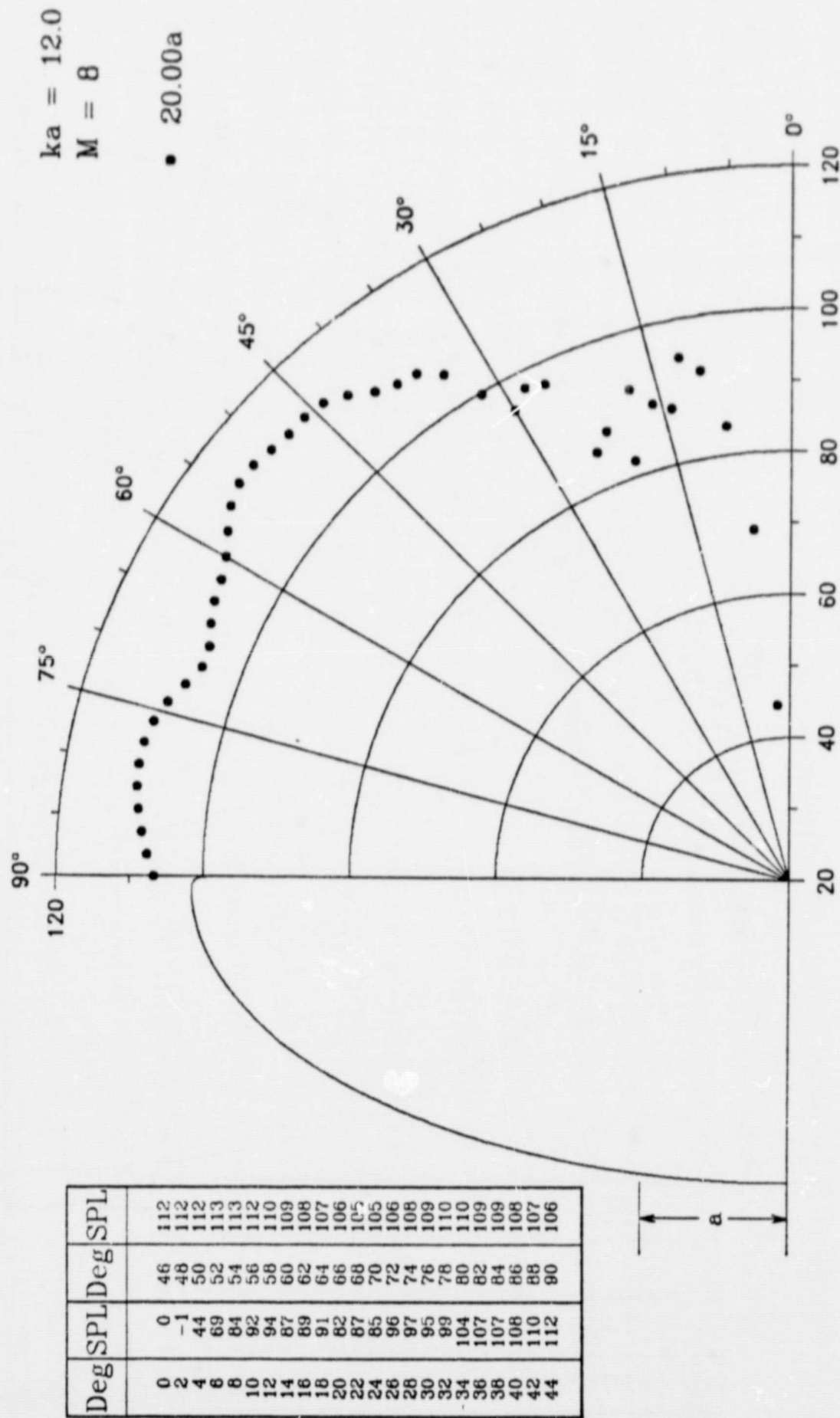


Fig. 90 SPL (dB)

PLANE BATTLE

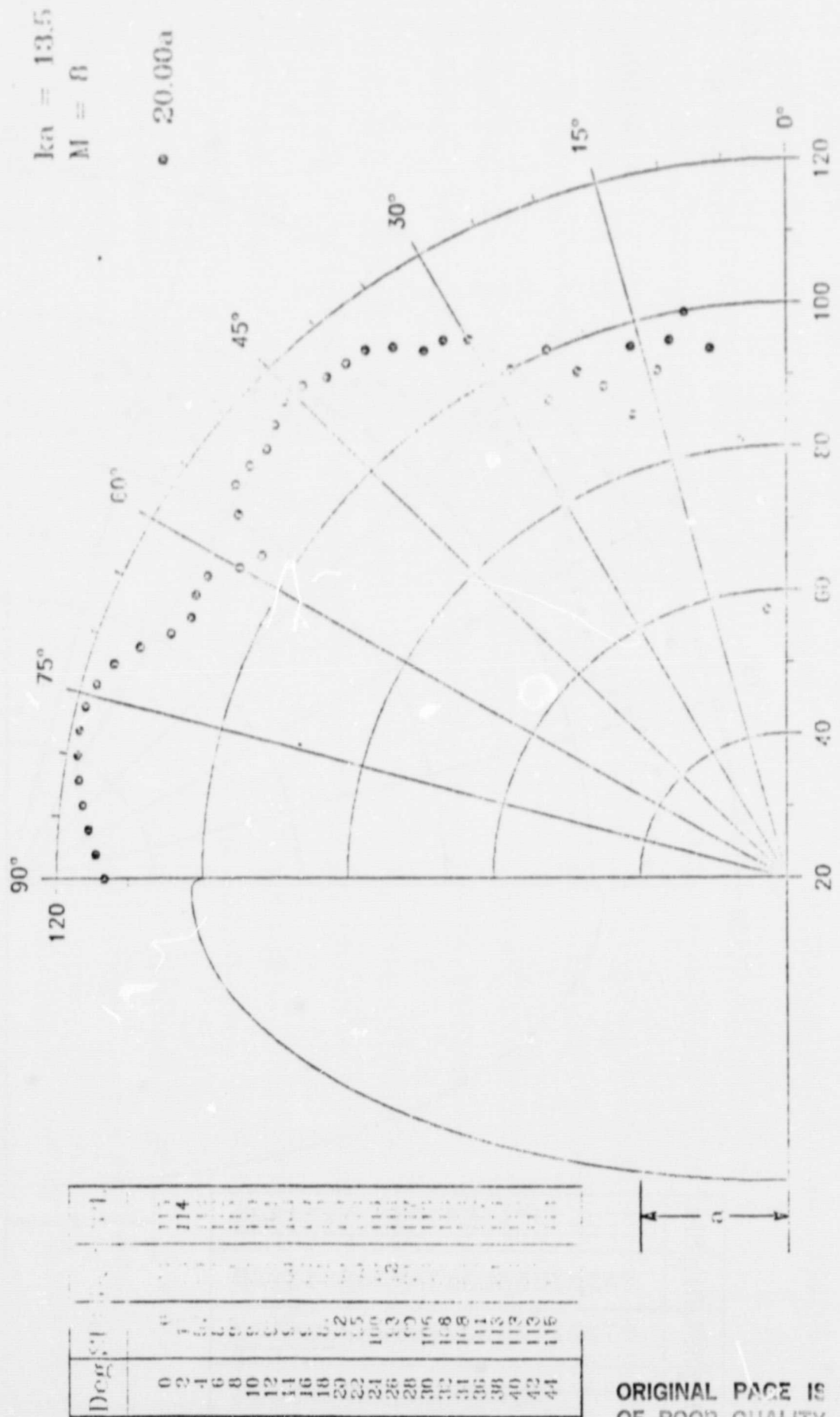


FIG. 91 SPL. (III)

PLANE BAFFLE

$ka = 14.5$
 $M = 8$
 $\bullet 20.00a$

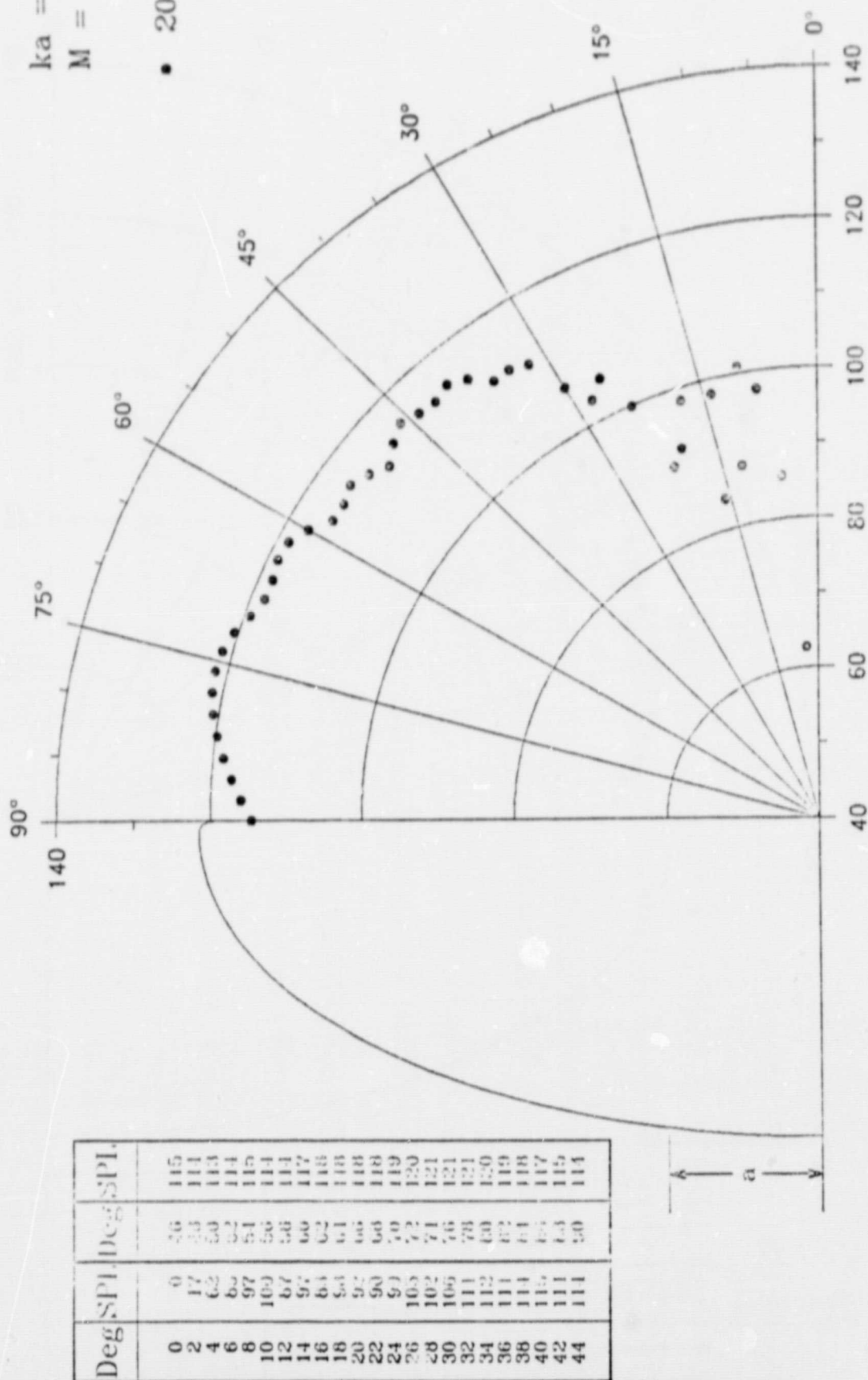


Fig. 92 SPL (dB)

PLANE BATHING

$ka = 16.0$
 $M = 8$
 $\bullet 20.00a$

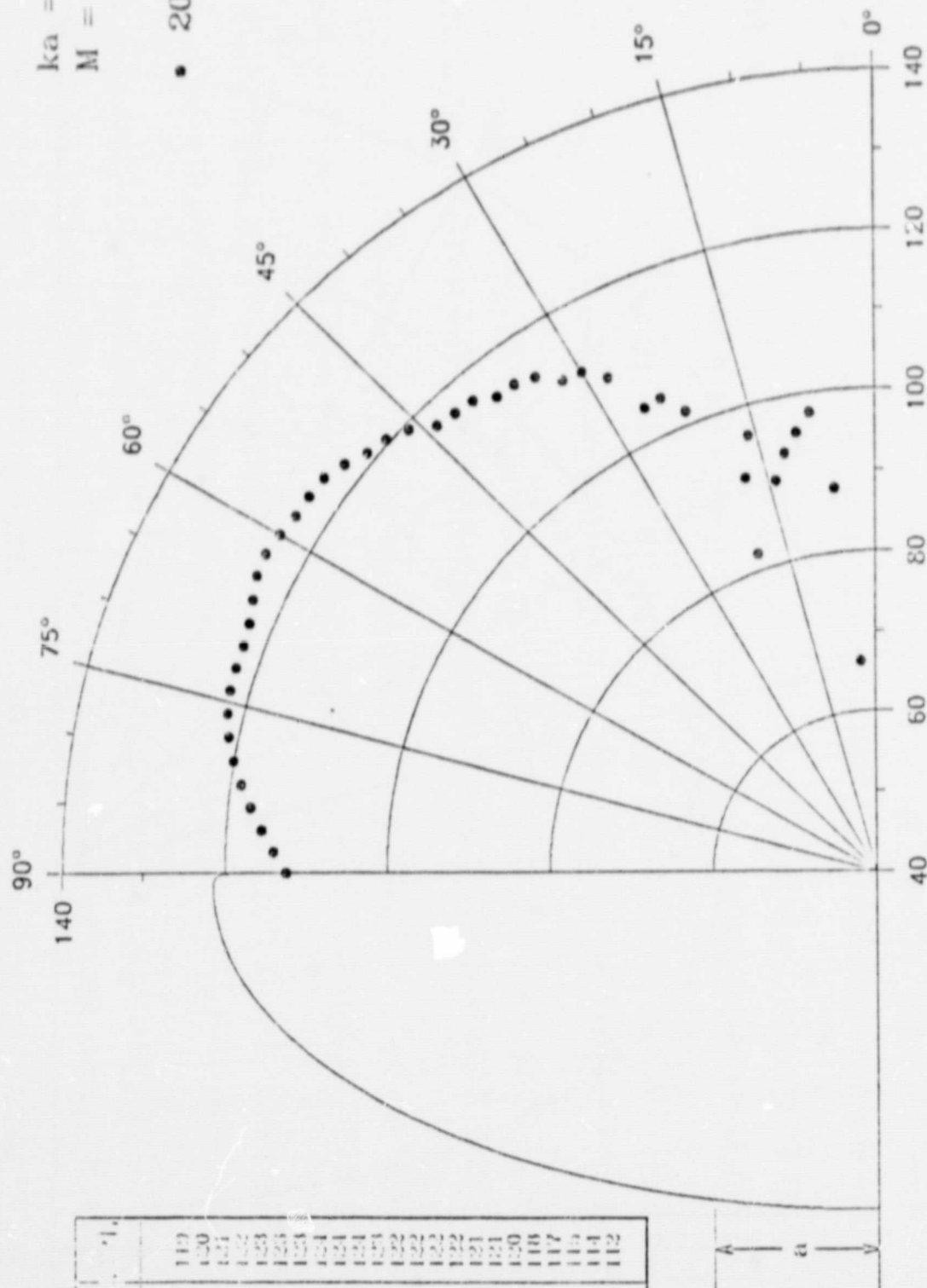
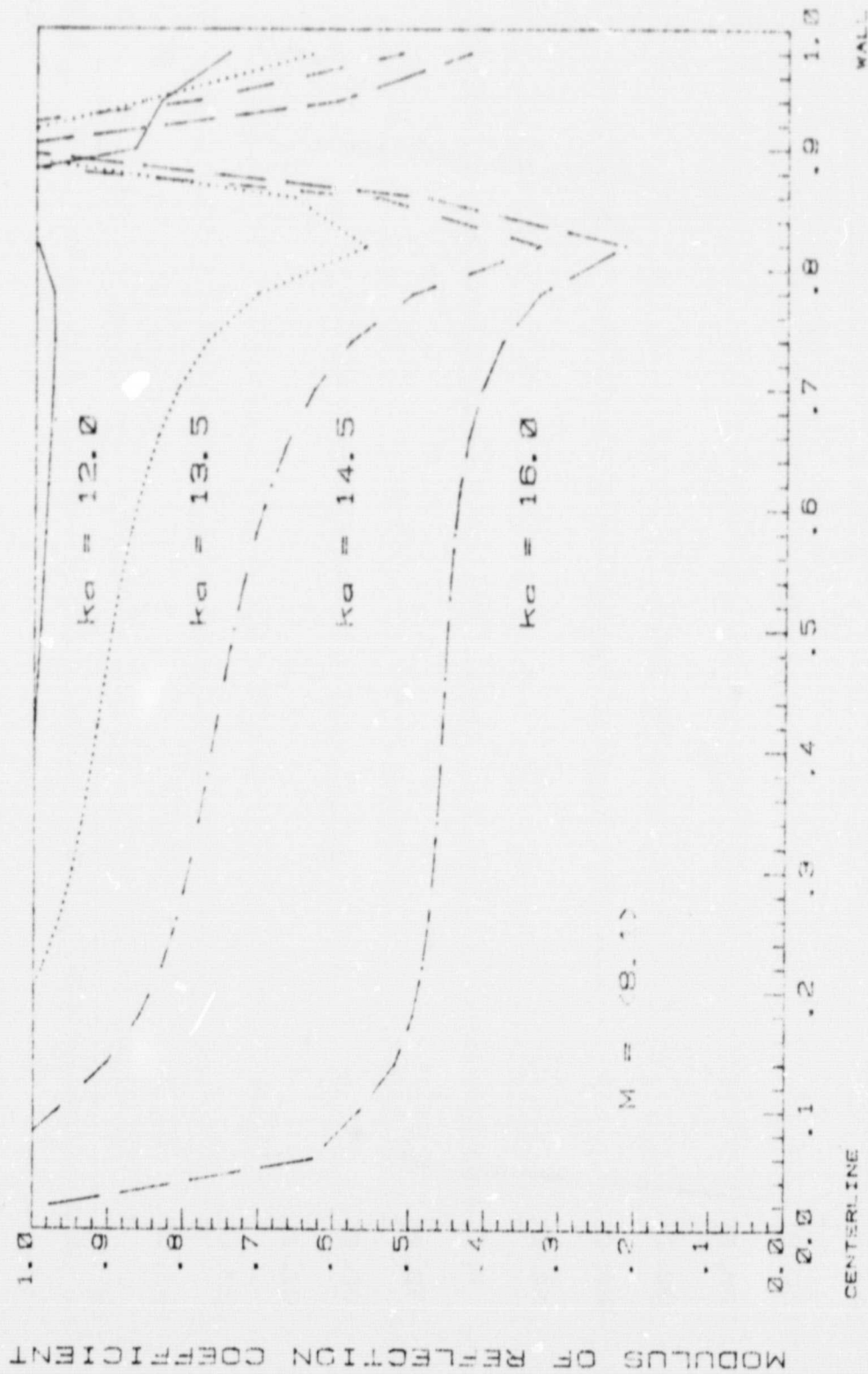


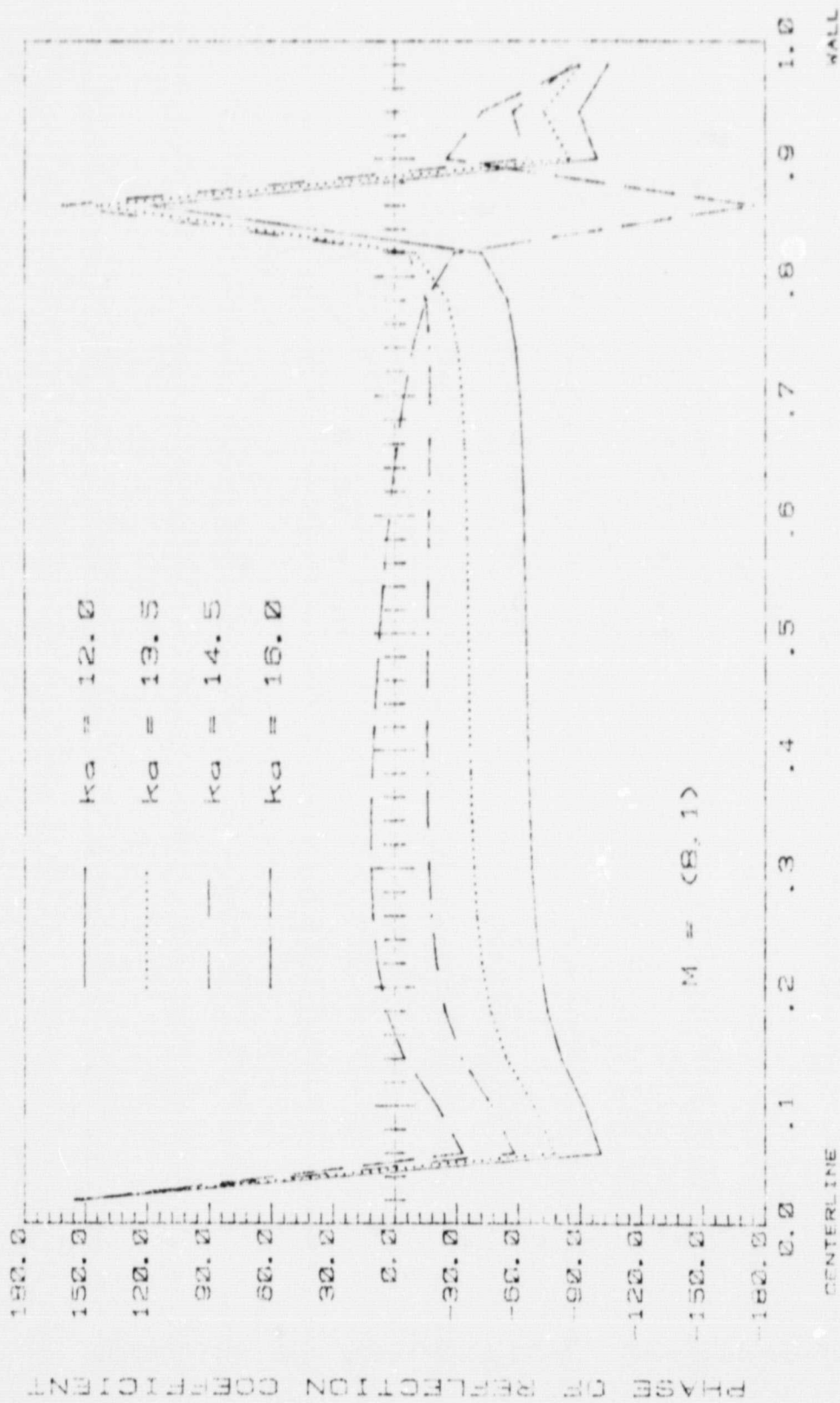
Fig. 93 SPL (dB)

Deg	SPL (dB)	Deg
0	0	119
2	21	120
4	66	121
6	87	122
8	97	123
10	95	124
12	93	125
14	90	126
16	86	127
18	81	128
20	72	129
22	63	130
24	50	131
26	41	132
28	32	133
30	23	134
32	14	135
34	5	136
36	-4	137
38	-13	138
40	-22	139
42	-31	140
44	-40	



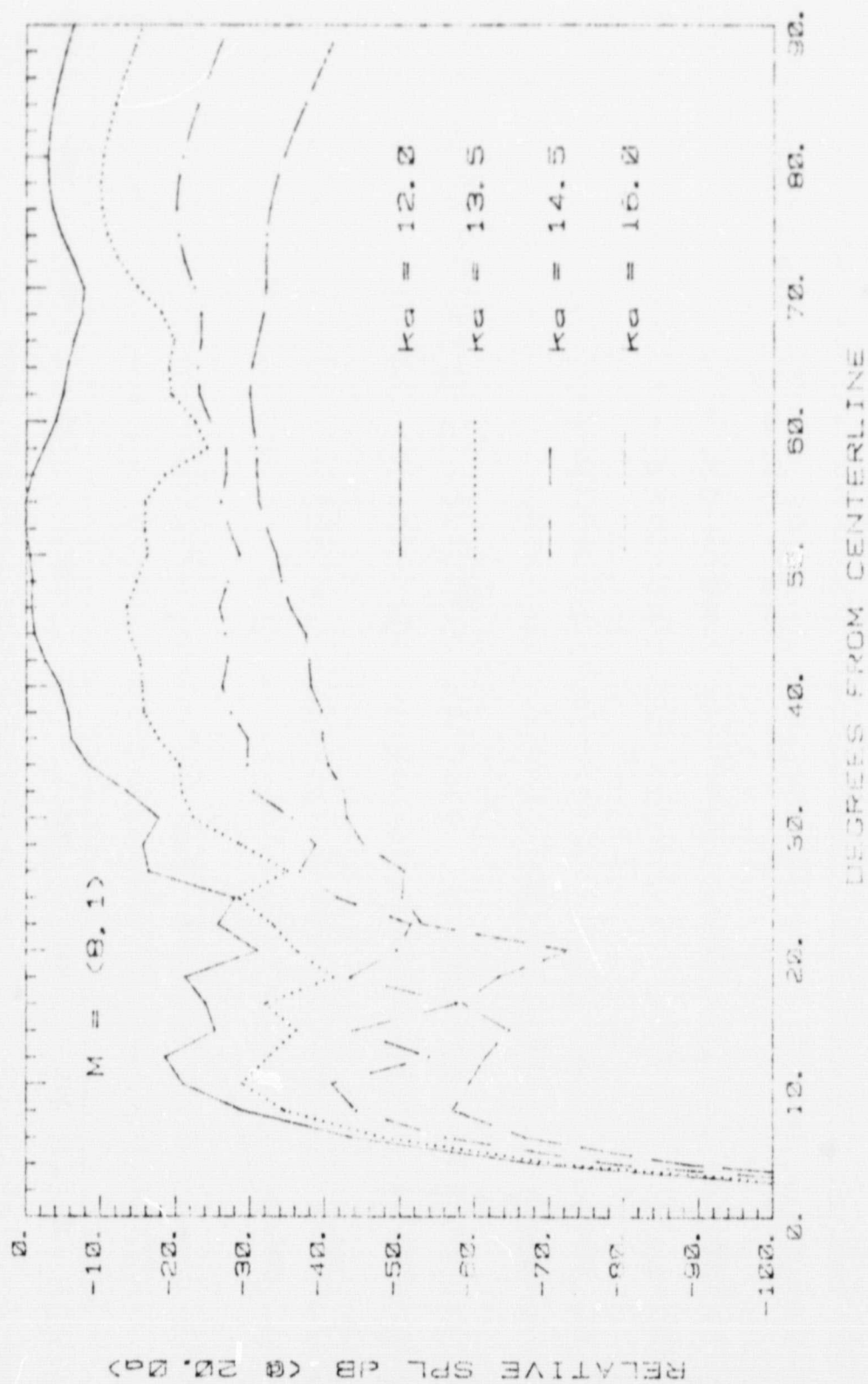
PLANE BAFFLE

Fig. 94



PLANE BAFFLE

Fig. 95



PLANE BAFFLE

Fig. 96

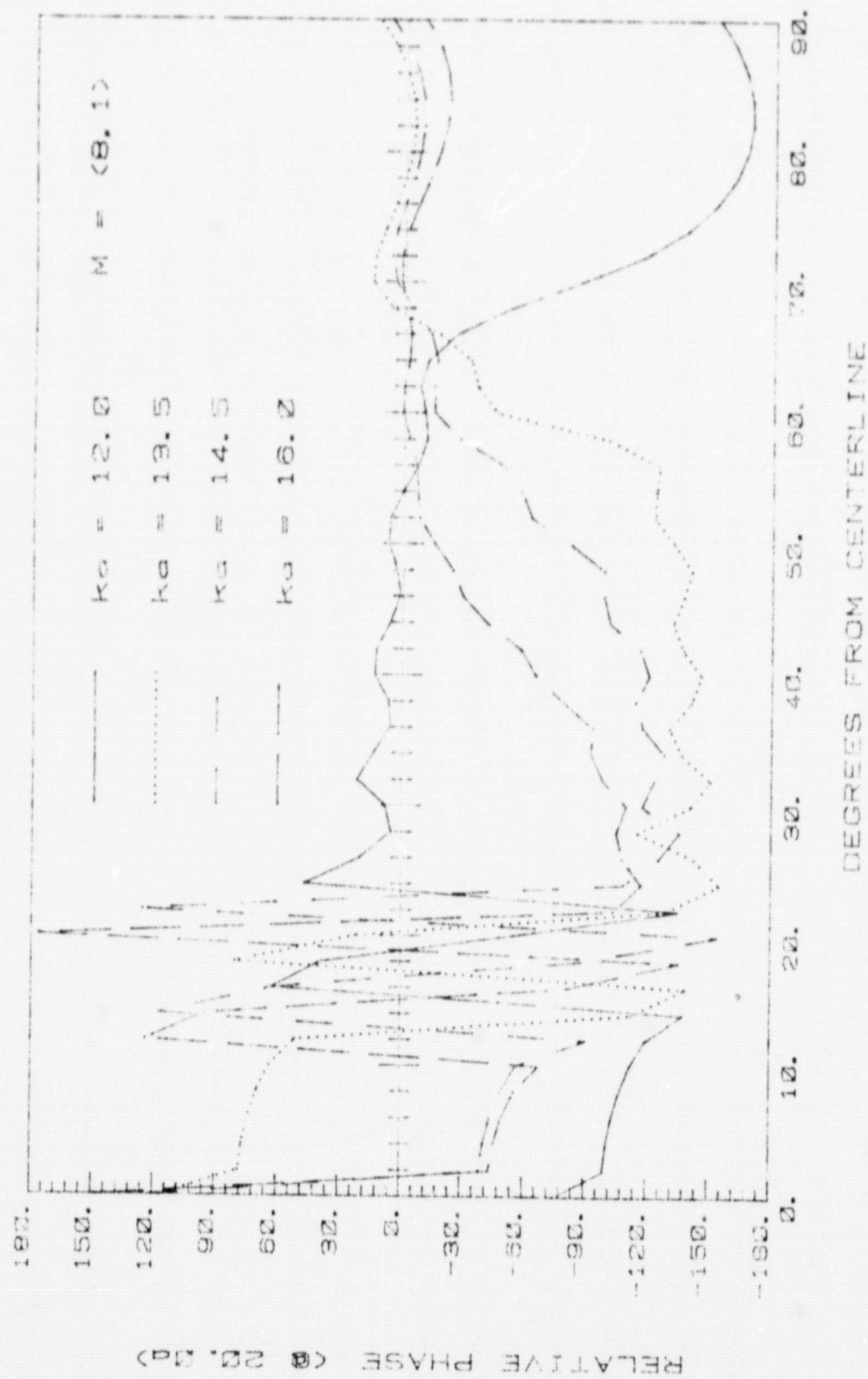


Fig. 97

PLANE BAFLE